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The Hell Gate Arch Bridge of the New York Connecting Railway over the East River in New York City.

Figs. 1 to 17, pp. 6 to 29.

We propose to give below a brief summary of the paper on the railway arch bridge known as the Hell Gate Bridge, built during the war over the East River at New York, which appeared in the *Proceedings of the American Society of Civil Engineers* in 1917. This notable bridge did not receive as much attention as it should have done in Europe, as it was built during the war. Although nearly 10 years have passed since it was built, it is such an interesting structure that it deserves to be better known by those dealing with the design and construction of bridges.

Short description and history. — The Hell Gate Bridge on the New York Connecting Railroad is a large steel arch bridge having a span of 995 ft. 1 3/8 in. between centre bearings, and a total height of 305 feet above mean high water level. It carries four railway lines on a heavy ballasted floor. The construction is in high carbon steel with riveted connections.

The river is 850 feet wide between banks at the site of the bridge and its greatest depth at high mean water is 105 feet. It was out of the question to think of permanent or temporary supports in the river channel itself. The only types which could be taken into account under such conditions were the cantilever or its relative the continuous truss, the stiffened suspension bridge, and the arch (hingeless, two, or three-hinged).

Most American engineers would have considered the cantilever type as best suited to the local conditions. The general opinion is that the suspension type is not suited for railway bridges if the span is less than 2 000 feet.

When the character of soil and other local conditions are considered, there is little difference in cost between the several types mentioned.

In 1904 Mr. Lindenthal made comparative designs of the three types comprising the stiffened suspension type, the three span continuous truss and the three-span cantilever with a central span of 850 feet and a total length varying from 1 450 to 1 550 feet. These designs are shown in figures 1, 2 and 3.

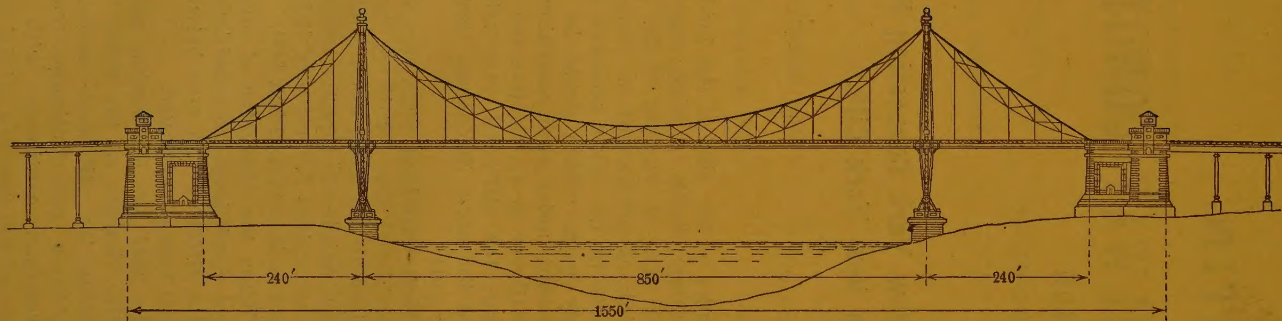


Fig. 1. — Suspension bridge design.

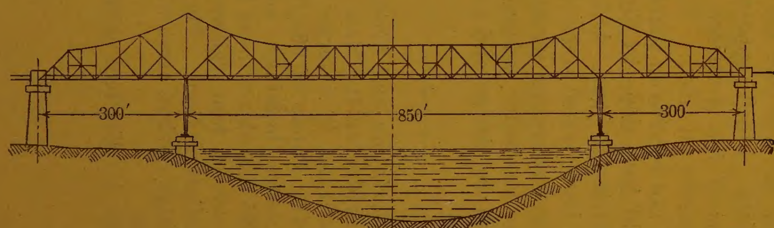


Fig. 2. — Cantilever design.

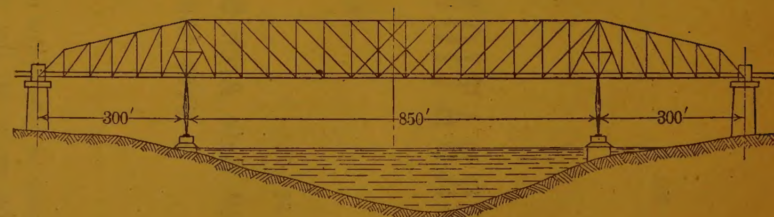


Fig. 3. — Continuous truss design.

The system of trusses adopted for the suspension design is that of an inverted three-hinged spandrel-braced arch suspended from hinged towers. The system is statically determinate. The upper chord or chain of eye-bars follows very nearly the equilibrium polygon for dead load. The centre hinge is necessary so that the system shall be immune to settlement of the foundations, as it was not known whether solid rock foundations could be found at a reasonable depth. When the piers are built on solid rock the centre hinge should be omitted.

The cantilever is generally superior to the suspension bridge so far as rigidity is concerned. The stiffening trusses in this design and the great sag of the chains (1/6 of the span length) have improved the suspension bridge in this respect, the deflections of which have been reduced to about one and one half times those of the cantilever. This great deflection is no serious disadvantage in the case of a bridge of such size, capacity, and dead load, which latter is double the maximum assumed live load and more than four times the live load under average traffic conditions.

The continuous truss is more rigid than the cantilever and suspension types. The trusses are, however, statically indeterminate and their stability may be dangerously affected by foundation settlement. Their appearance is less pleasing.

In 1905 the plan of the line was altered bringing it almost on to the shore line of the island and altering the central span. These conditions induced Mr. Lindenthal to investigate a single span arch bridge design with a span length of 1 000 feet between supports. Comparison of cost with the suspension and cantilever designs showed a saving in favour of the arch.

The weight of steel work of the arch was 13 000 tons as compared with 14 000 tons and 17 000 tons for the suspension and cantilever designs respectively. The arch type is also more rigid and the vertical deflections are only about two-thirds those of the cantilever type. The secondary stresses are regularly smaller in an arch of this type than in a cantilever.

The economy of an arch depends largely on the method of erection. The material needed for the viaduct spans, etc., provides ample material to make up the temporary back stays and anchorages at little cost.

Comparative designs of arch bridges. — Two types of double hinged arch were prepared — the spandrel-braced arch like the Rhine bridges at Dusseldorf and Bonn (595 and 614 feet spans), and the crescent arch like those over the Garabit valley (France), and the Douro River in Portugal (541 and 525 feet spans). (Figs. 4 and 5.) The weight was slightly in favour of the crescent arch, but the spandrel-braced arch offered greater advantages for the cantilever erection.

The three hinged arch was not considered as being not so cheap as the others, and also less rigid. The fact that the two hinged arch is statically indeterminate is considered to be without objection when the abutments rest on solid foundations.

So far as the arch itself is considered, the stresses in the three hinged arch can only be determined statically so far as the exterior forces are concerned, as riveted connections and even pin connections are all now recognised to be indeterminate.

Description of the structure. — The structure as built is a spandrel-braced steel arch bridge with two hinges at the ends of the lower chords. The span between hinges is 997 ft. 6 in., and was determined indirectly, as the clear height had to be 135 feet above mean high water for a width of 700 feet for navigation. The upper corners of this clear-

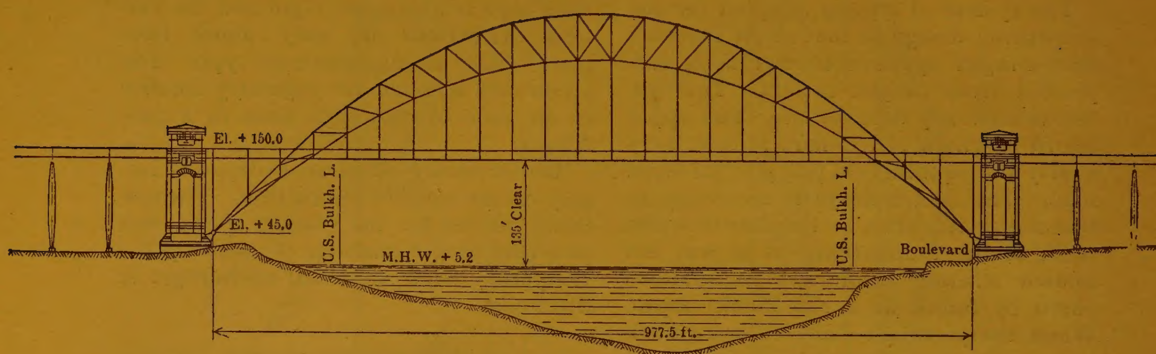


Fig. 4. — Crescent arch design.

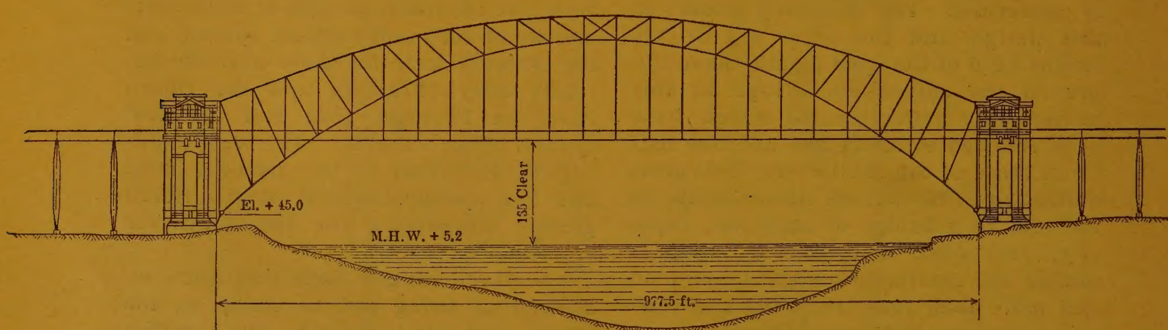


Fig. 5. — Spandrel-braced arch design.

ance rectangle fixed the intersection points of the floor with the bottom chord.

The exact rise of the centre line of the bottom chord is 220 ft. 0 in. above the centre of hinges, which gives a ratio of rise to span length of 1 : 4.5. This ratio is the most economical under the given conditions. The weight of an arch of this type and length varies inappreciably for variations in rise between 1/6 and 1/4 of the span, the minimum being nearer the lower value.

Shape of bottom chord. — The panel points of the bottom chord lie on a parabola, this being the line of equilibrium of the bottom chord as an independent arch and when covered with a uniform load equally distributed over the whole span.

This condition was nearly realised during erection, the bottom chord being erected with the joint at one of the centre panel points acting as the middle hinge.

Height of arch trusses. — The total height from centre of hinge to centre of top chord at the middle of the span is 260 ft. 2 5/8 in., and the total height of the steel super-structure above mean high water is 305 feet.

The height of the trusses at the quarter points is 60 feet or rather slightly more than 1/4 of the rise of the bottom chord. The height of the trusses at the centre was decreased to 40 ft. 2 5/8 in., or

about 1/24 of the span, and the height of 140 feet at the ends of the trusses was determined by the necessity for rigid portals between the end posts above the track floor.

Width. — The width of 60 feet between centres of trusses resulted from the required width of 53 feet for the four tracks (the distance between centres of tracks being 13 feet) and an allowance of 7 feet for the width of the bottom chord at its intersection with the floor.

This width being 1/16 of the span length was sufficient for lateral stability and rigidity.

The floor is made 93 feet wide, its chords being placed 16 1/2 feet outside of the main trusses and carried by cantilever extensions of the floor beams, in order to give great lateral rigidity of the suspended floor and an economical floor wind truss.

Web system. — The main trusses consist of a single line of verticals and diagonals in N form, the latter falling towards the centre, the average inclination of the diagonals being about 45° with the horizontal. The length of the panels is 42 ft. 6 in., there being 23 panels, or an odd number.

General arrangement of arch bracing. — The transverse bracing between the two trusses comprises lateral systems along the top and bottom chords and sway frames and portals in the planes of the first five verticals at each end of the span.

Sway frames between the other truss verticals were omitted purposely in order not to overweight the structure. They would have had to be very heavy to resist the stresses from unequal deflection of the two trussses under one-sided load.

General arrangement of the flooring. — The floor system comprises (fig. 13):

1. Floor beams riveted to the verticals of the end panels and hung from the trusses by suspenders in the middle part;
2. Eight lines of stringers 6 ft. 6 in. apart framed into the floor beams. These stringers carry in pairs reinforced concrete troughs in which is the ballast for the track between the main trusses.
3. Four lines of foot way stringers framed into cantilever extensions of the floor beams made strong enough to carry the tramway lines which had been contemplated;
4. Two lines of lattice girders screening the floor system and acting as railings;
5. A floor lateral truss to resist the wind and lateral forces;
6. Two « braking girders », one at each intersection of the floor with the main trusses. These girders transmit the longitudinal forces from braking and traction from the stringers to the main trusses and thus eliminate serious horizontal bending of the floor beams.

Provision for expansion of the floor. — The floor had to have at least one expansion joint so as not to be strained by temperature changes or deformation of the arch truss. The joint had to be at or about the intersection of the floor with the bottom chord.

The expansion of the floor for a change in temperature of $\pm$ 72° F. is $\pm$ 4.1 inches, partly absorbed by the horizontal expansion of the arch of $\pm$ 1.6 inches between these points. The remaining expansion of $\pm$ 2.5 inches had to be provided for at the expansion joint. The effect of a maximum live load covering the centre span is to open the joint by 0.1 inch which is negligible.

The following considerations had to be taken into account when locating the expansion joint:

1. To secure the greatest lateral rigidity, the joint should cause the least lateral deflections;

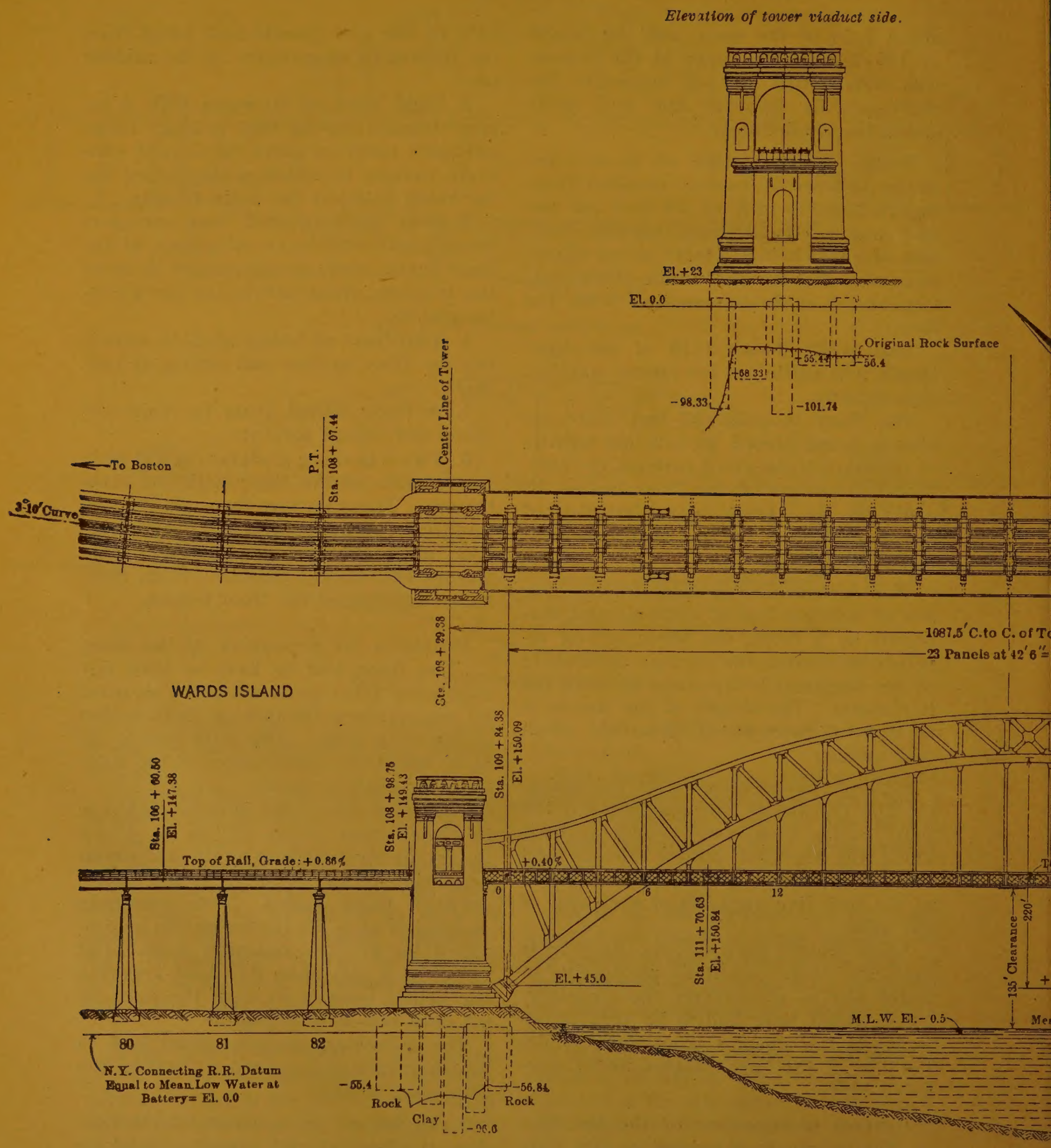
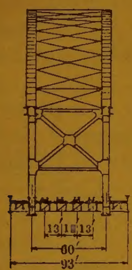
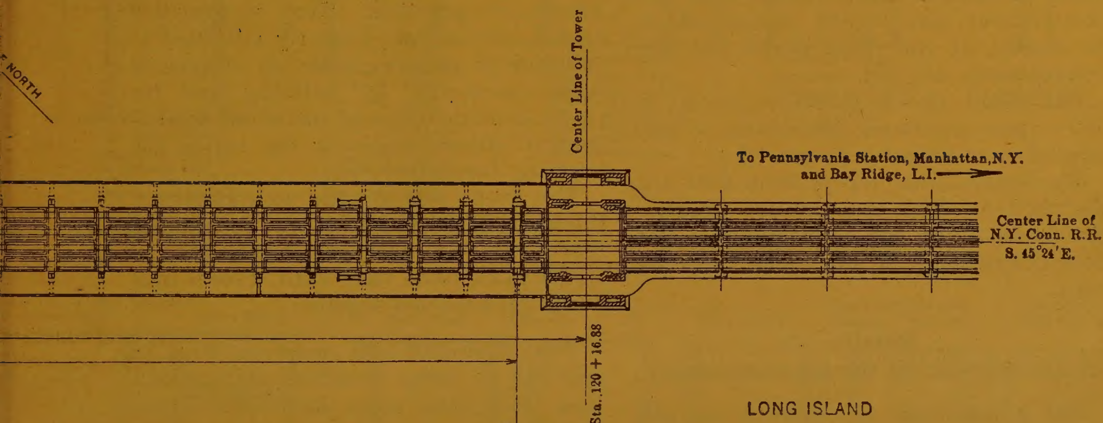
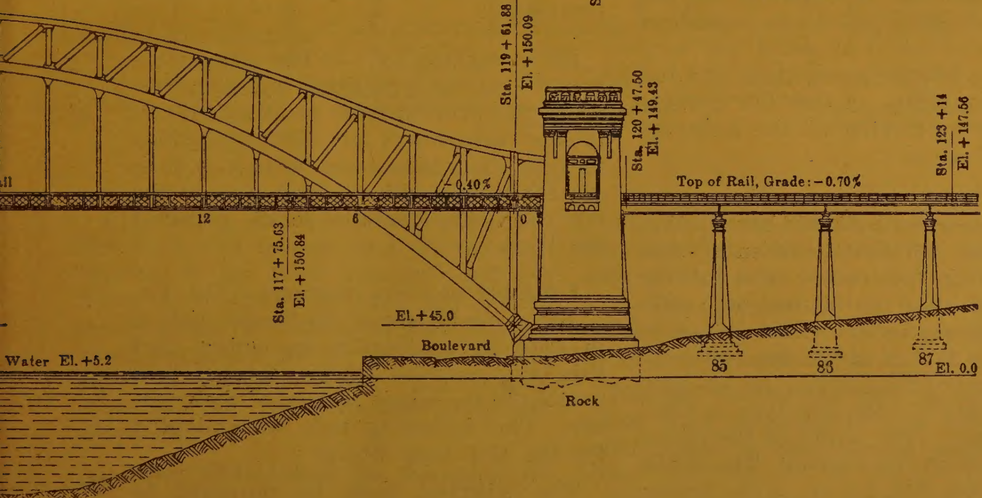


Fig. 6. — General plan of Hell Gate Bridge and

ross section at intersection of floor-bottom chord.







ions of Wards & Long Island Viaducts.

2. To avoid large stresses in the stringers and their connections from the longitudinal force, the distance between the expansion joint and the braking girder should be as small as possible;

3. The floor suspenders should be subject to the least possible bending in the plane of the truss.

To best meet these conditions the expansion joint was placed at panel point 12, six panels from the Wards Island end. At the corresponding point 12 on the Long Island side the floor laterals are rigidly connected at the centre of the floor beam, but the wind chords are cut.

The wind chord therefore forms a three span cantilever truss with a suspended span between points 12.

The longitudinal forces from 0-12 are absorbed on each side by the braking girders in *b* and the connections to the floor beams made strong enough accordingly.

Details of construction of the superstructure.

The connections are riveted, no pin connections being used. In members subjected to reversal of stress, pin connections are insufficiently rigid and impair the durability; so that the connections could be riveted all the members have double webs.

Bottom chord section. — The bottom chord has a closed double-box section with a solid horizontal stiffening diaphragm along the centre line of the chord. The area of the section varies from 929 square inches at the crown to 1 392 square inches at the bearings.

The corresponding surface for the new Quebec bridge of 1 800 feet span is 1 902 square inches. The width of the chord is 6 ft. 6 1/2 in. throughout. The depth increases from 7 ft. 1/4 in. at the crown to 10 ft. 9 3/4 in. at the bearings, the greatest depth overall being 11 ft. 4 1/4 in. The thickness of the web is uniform and the depth at the bearings is the largest that transportation from the shop to the site would allow.

The webs are formed from two plates riveted along the horizontal centre line and are stiffened by five pairs of transverse diaphragms.

The closed double box section was used here for the first time in a large structure. The circular tube section of the Forth bridge is theoretically the best to resist buckling, but is too costly for American practice. The rectangular closed box section properly stiffened is superior to sections made up of several webs connected by latticing and tie plates provided it is of sufficient dimensions to allow access to the inside for riveting, inspection, etc.

The webs are of the extraordinary thickness of 2 inches. It was considered that greater strength is obtained with a single thick plate than with several thin plates tack-riveted together.

Top chord and web members. (Figs. 10 and 11.) — These members are box section. All open sides have stiff angle latticing.

Floor suspenders. — The suspenders are of I section with single web 48 inches deep. To prevent large bending stresses in the suspenders at the connections with the floor beams and the trusses, they are connected with 16-inch pins at the top and bottom parallel to the plane of the truss.

Latticing of truss members. (Fig. 8.). — Since the failure of the Quebec bridge in 1907, it is generally recognised that this latticing should bear a proper proportion to the whole section of the member. The following rule was adopted for the Hell Gate Bridge :

The latticing shall be designed to resist at right angles to the main member a shearing force in pounds at least equal

to 300 times the gross area of the member in square inches.

Actually the latticings were built up of angles of a minimum thickness of 1/2 inch with two rivets for each angle at least. Flat lattice bars are not recommended. They are easily bent in handling, which constitutes a permanent defect in a bridge.

The inclination of the bars is about 45° with a splice at the intersection with a square covering plate.

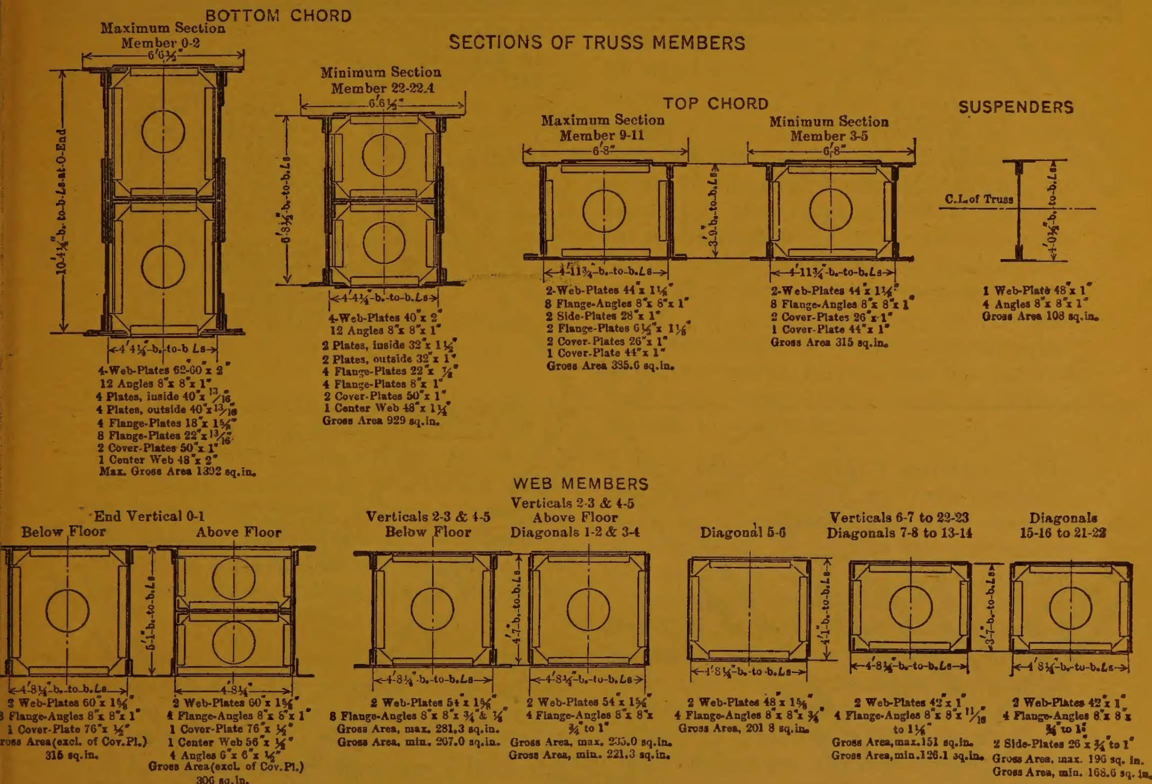


Fig. 7.

Riveting. — Little is known about the distribution of stresses in a riveted connection; it has been assumed that the rivets were equally stressed, any differences arising from the secondary stresses being supposed to be covered by the factor of safety. Certain requirements were adopted, the principal being the following:

— The joints shall be designed of equal strength to that of the member;

— The joints shall be calculated for the maximum stress both in compression as well as in tension;

— The joints shall be fully spliced; otherwise the number of rivets must be increased by one third.

The top chords are fully spliced; the joints were designed to take the maximum stress in compression or in tension.

For parts under tension this condi-

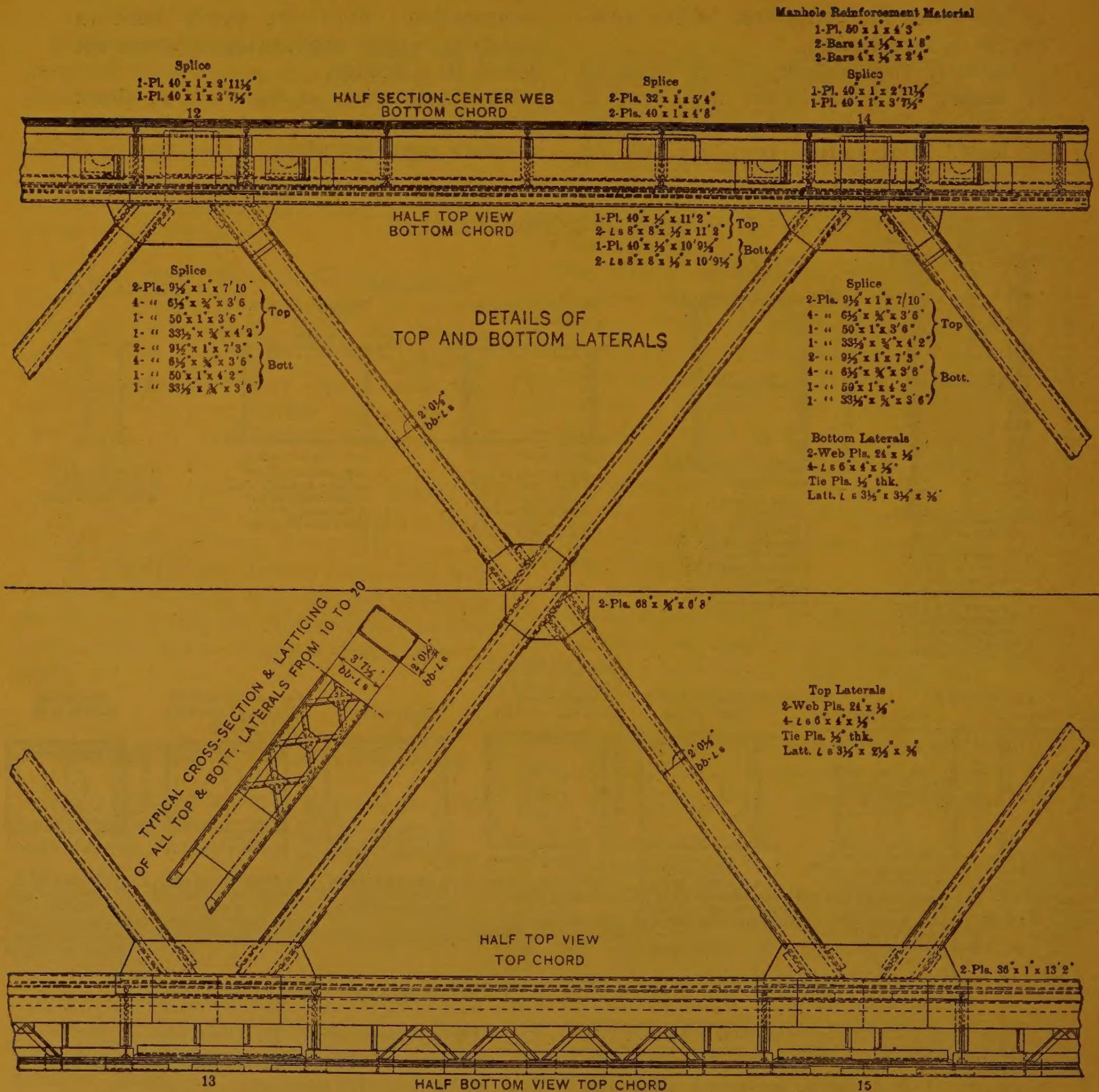


Fig. 8.

tion is obviously necessary, but for those in compression it might be thought that the joint was of less importance. In present day practice it is considered that even in such a case the joint should be able to carry the total load.

It must be noted that in practice in addition to main compression stresses, secondary bending stresses occur, which give rise to stresses in tension at the joint. Furthermore defects of workmanship may result in imperfect contact be-

tween the faces of parts of the members.

Joints in bottom chords. (Fig. 12.) — The joint between two compression members of the bottom chord adopted was of unusual design. The end of one of the chord members meeting at a joint was faced to a perfect plane, and that of the other member was faced to three planes, so that the joint was tight over the middle third of the chord depth and each outer third formed a wedge shaped opening 1/8 inch wide. The purpose of this arrangement was to concentrate the bearing pressure over the middle part of the joint and thereby avoid dangerous edge pressures. Experience with other large bridges fully justified this precaution.

The outer thirds of the joints are spliced 100 %, the middle third only about 50 %.

The area of the splicing material of the whole joint is between 70 and 80 % of the effective area of the chord, but its section modulus is practically equal to that of the main section. Including the bearing area of the middle third of the main section, the total resisting area to compression is from 110 % to 120 % of the chord section.

Rivets. — The maximum diameter of the rivets is 1 1/4 inches for the bottom chord, the thickness of the plates to be riveted amounting to as much as 9 7/8 inches. The other rivets are 1 inch and 7/8 inch.

Wind and lateral bracing. (Fig. 8.) — The wind bracing between chords is made up of intersecting rigid diagonals in the form of a St. Andrew's cross without transverse struts, except at the panel points at each end where they form part of the sway frames or portals.

Laterals are commonly proportioned to resist the stresses from wind and other lateral forces.

The fact is generally overlooked that the lateral system between compression chords bears to these chords the same relation as the latticing to the different ribs making up a compression member, and helps to strengthen the two chords against lateral buckling as a whole.

In accordance with this hypothesis the laterals and their connections should be strong enough to fulfil this requirement independently of the calculations of wind froce. The following rule was adopted :

If a be the gross section of the compression chords in square inches (the mean if the chord section varies), the laterals in any panel should be designed for a shearing force in pounds $S = 400a$, $330a$ or $300a$, if the lateral system connects two, three or four trusses respectively. It is not necessary to combine this force with the shear from the wind or other lateral forces, but the laterals and their connections must be strong enough to resist either.

Arch bearings. (Figs 9 and 14.) — The bearings are of cast steel and transmit to the granite skewbacks a total reaction of 30 262 000 lb. or 700 lb. per square inch on a bearing area 17 ft. 6 in. square.

The upper shoe at the end of the chord is in two pieces each weighing 30 tons. The lower face is perfectly plane and bears against the convex cylindrical surface of the lower shoe, the radius r of which is 1 150 inches.

The maximum angular motion under load is approximately 1° 30′ up or down which produces an eccentricity of only 2.5 inches. The pressure per lineal inch of line of contact is

$$p = \frac{30\ 274\ 000}{116} = 261\ 000 \text{ lb.}$$

The contact is over a rectangular area of width

$$b = \sqrt{\frac{pr}{E}} = 9.5 \text{ inches,}$$

E = modulus of elasticity of the material.

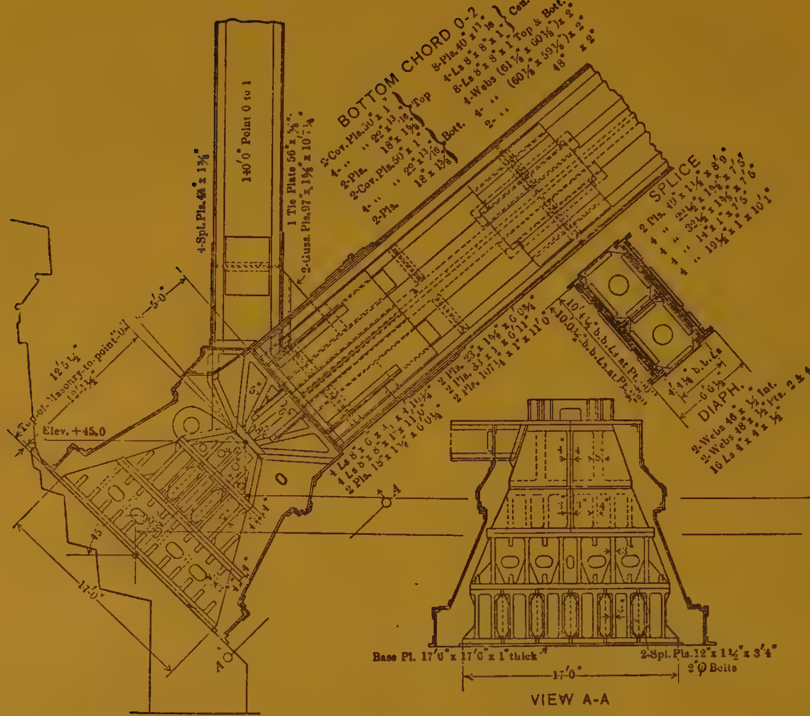


Fig. 9. — Details of panel point O and bearing.

The maximum pressure per square inch at the centre :

$$S = 0\,42 \sqrt{\frac{pE}{r}} = 34\,500 \text{ lb per sq. inch.}$$

The average pressure is 27 500 lb. per square inch.

The maximum tangential force is 3 570 000 lb. or 12 % of the normal pressure, and is easily resisted by the friction of the supports. However, to prevent displacement of the upper shoe, four steel dowels 5 1/2 inches in diameter are set into the lower shoe and engage holes in the upper.

The lower shoe is in eleven pieces arranged in three rows in which the joints are placed alternately parallel and at right angles to the plane of the truss to ensure proper distribution of the pressure.

A one-inch steel plate is placed between the lower shoes and the masonry. Sixteen anchor bolts 2 1/2 inches in diameter and 10 feet long secure the lower shoe to the masonry.

Particular attention was given to this cast steel bearing as the failure of the Quebec bridge in 1907 was attributed to defects in this part.

It is essential that the cast steel be properly annealed, that the thickness throughout the casting be uniform, and that the cores be removed quickly after casting, so as not to interfere with the free contraction of the casting. In short, initial cracks must be avoided and high internal stresses removed.

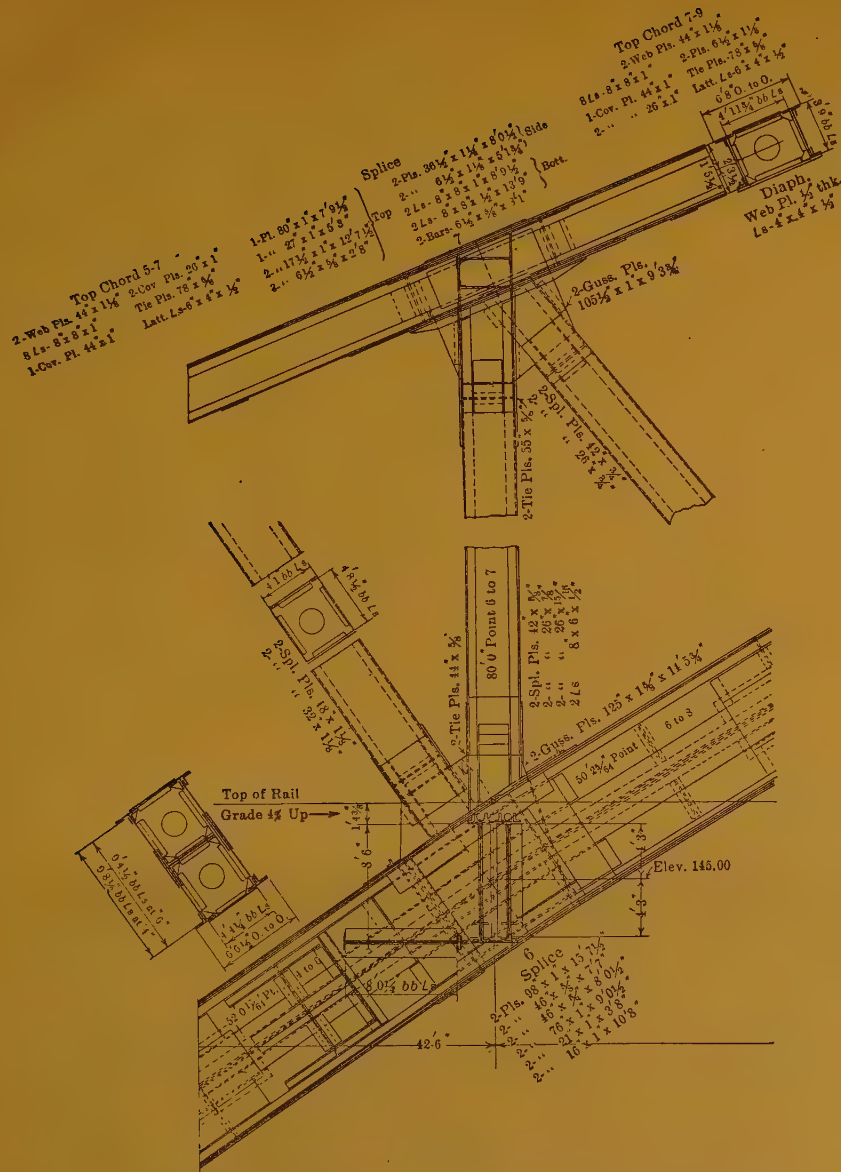


Fig. 10. — Details of panel points 6 and 7.

Stringers and floor beams. (Figs. 11 and 13.) — The railroad stringers are 6 feet deep and of ordinary make up. They are connected in pairs by top and bottom lateral bracing and two sway frames in each panel. The floor beams are heavy box girders with two webs 8 ft. 6 in. deep with top and bottom

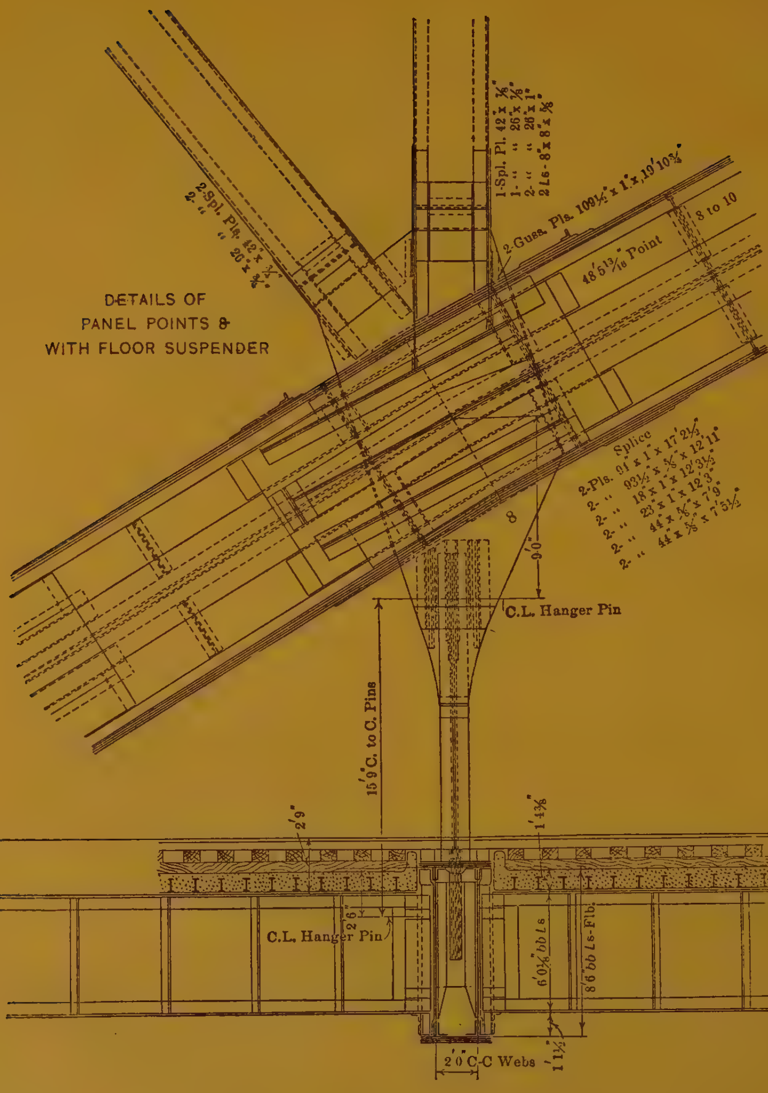


Fig. 11.

cover plates 42 inches wide. They are stiffened by vertical diaphragms opposite the floor lateral connections and are connected to the floor suspenders by 16-inch pins.

Each of the floor beams weighs 86 tons.

Floor lateral truss and braking girder. (Fig. 13.) — The diagonals are riveted to the stringers and to the floor beams.

The two braking girders are rigidly framed into the bottom chord of the arch trusses at the intersection with the

floor. They have a single web 8 feet deep placed immediately below the floor laterals.

Camber and deformation of arch trusses. — The arch trusses were cambered for dead load only. The camber was ascertained by increasing or decreasing the « geometric » length of each member by an amount equal — but opposite — to its change in length from its dead load stress. The object was to prevent the top of the rail from sagging below a horizontal line under full live load and extreme low temperature.

The stresses due to live load have little influence on the deflections.

The deflections were calculated on the gross area of all members. The modulus of elasticity was assumed to be 30 000 000 lb. per square inch. The maximum deflection under dead load is 8.35 inches, the average dead load being 51 000 lb. per lineal foot.

Under a live load of 12 000 lb. per foot of truss covering one half span, the maximum deflection at about the quarter point is 5.19 inches or $\frac{1}{2\,300}$ of the span.

The deflection for temperature variations of $\pm$ 72° F. from a mean temperature of 60° F. is 0.74 inch per degree; the maximum being $\pm$ 5.3 inches or $\frac{1}{2\,250}$ of the span.

Steel. — High carbon steel of high elastic limit was used in the construction of the arch trusses. The use of nickel steel was also considered, but it was found that in spite of the 50 % increase in permissible unit stresses there was no saving in cost.

Specification of high carbon.

Chemical composition :

Carbon	0.27 to 0.34	Phosphorus	0.04 to 0.06
Manganese	0.52 to 0.64	Sulphur	0.05

Tensile strength :

Breaking strength	66 000 to 76 000 lb. per square inch.
Apparent elastic limit	38 000 lb. per square inch.

Loads and unit stresses. — The Engineers endeavoured to determine as accurately as possible the nature and maximum value of the stresses acting. Having done this, working stresses relatively high in relation to the limit of elasticity (5/8 to 3/4) were permitted.

Dead load. — The dead load has been calculated as follows :

Track and flooring in armoured concrete, conduits, etc.	14 000 lb.
Steel work	37 000 lb.
Total average dead load per foot of bridge	51 000 lb.

The dead load actually varies from 45 000 lb. at the centre to 62 000 lb. at the ends.

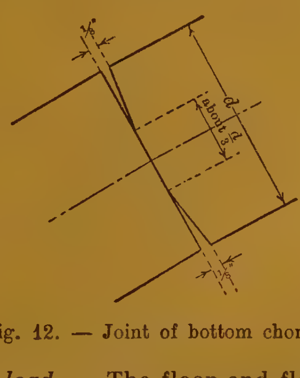


Fig. 12. — Joint of bottom chord.

Live load. — The floor and floor suspenders were designed for Cooper's E-60 live load, partly consisting of 4 axles loaded to 60 000 lb. at 5-foot centres on each of the four tracks, or an alternative

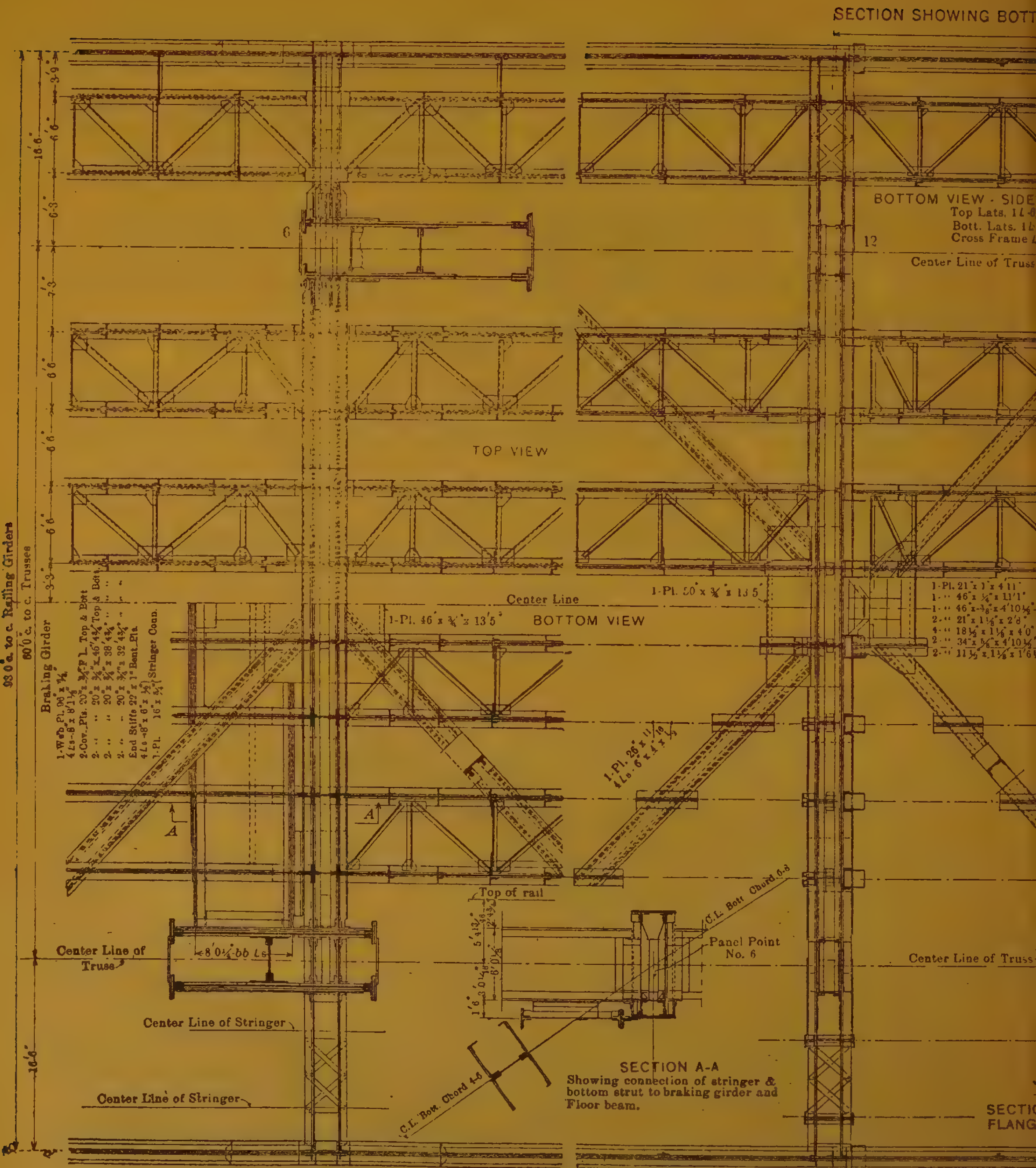
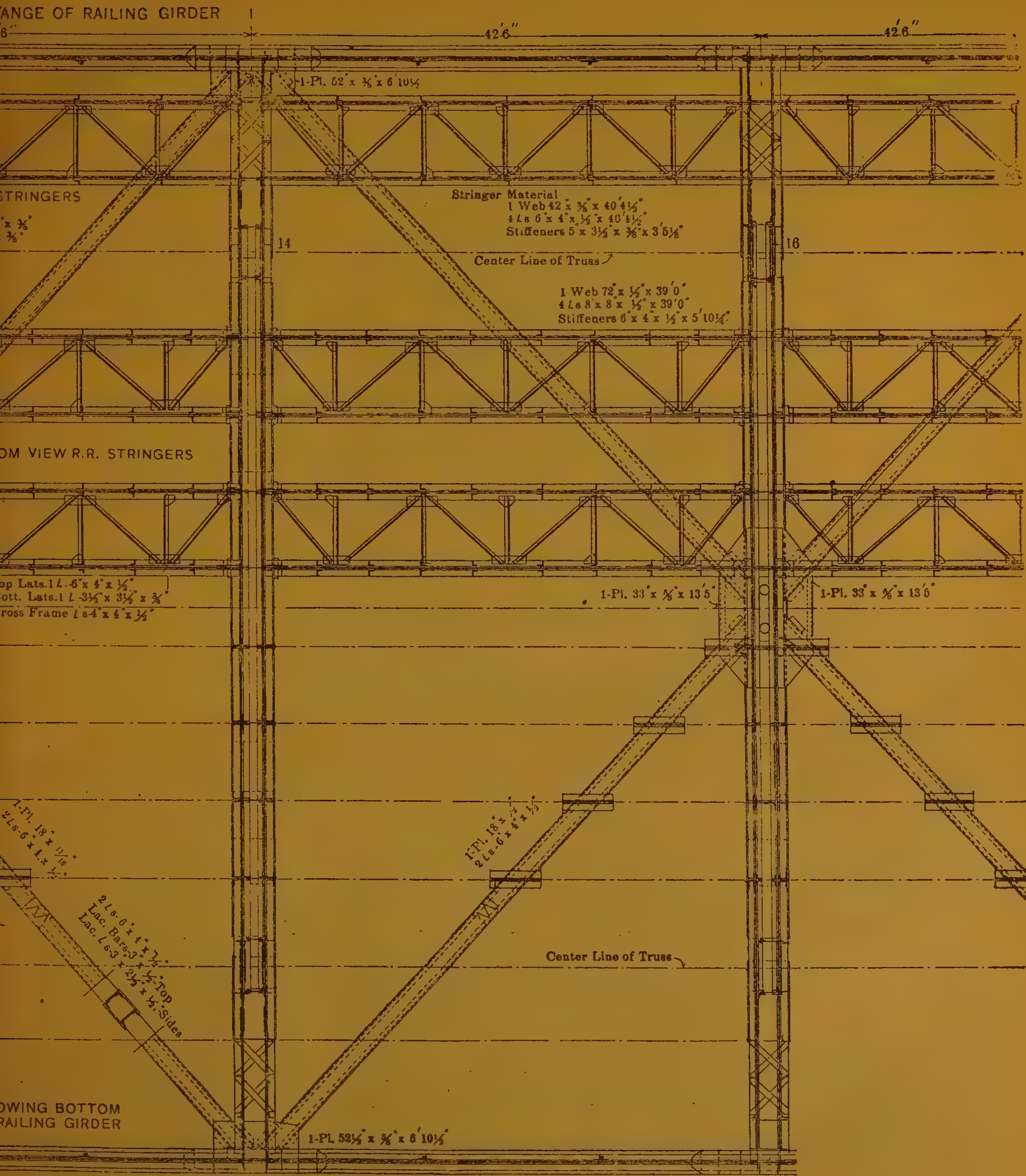


Fig. 13. — Details of floor



m and braking girders.

three axle load of 70 000 lb. on each axle at 7-foot centres wherever this causes higher stresses.

The arch trusses were designed for a uniform load of 6 000 lb. per foot of track or 24 000 lb. per foot of bridge. This method was justified in view of the highly improbable condition of maximum engine and car loads in the most unfavourable position on all four tracks at the same time. This condition would have required additions up to about 5 % on the sections of some of the truss members.

Impact. — The increases due to impact were calculated by Lindenthal's formula, applied to E-60 loading :

$$I = \frac{L^2}{D + L} \times \frac{1200 + \frac{a}{n}}{600 + 4a}$$

D = stress from dead load in pounds;
L = stress from live load in pounds;
a = length of train behind tender for position of maximum stress in feet;
n = number of tracks loaded for maximum stress.

The coefficient n is explained by the fact that the locomotives may give full impact on each track, whereas the trucks affect one track only.

The author considers this formula can be used for all spans and all types of flooring. The usual American formula gives excessive results for long structures and insufficient values for short structures especially in the stringers.

Lateral force for live load. — For the first time in an American specification the lateral force due to moving trains has been separated from the lateral force due to wind. None the less the action of centrifugal force has been included in the same figures. On tangents or curves up to 2° the force has been assumed at 600 lb. per lineal foot of single track.

For curves sharper than 2°, 300 lb. was added for each degree up to 6°.

These forces were increased 50 % for each additional track.

For a four track structure on the straight the lateral force to be allowed for is 1 500 lb. per foot.

These forces are considered to be higher than those actually met with in practice.

According to the American Railway Engineers Association 1914 specifications, the total combined force due to the moving train and wind pressure is only 800 lb. in such a case.

Wind. — The transverse stress due to wind was assumed to be equal to a moving load of 500 lb. per lineal foot of bridge at track level, plus a static load of 30 lb. per square foot on all such vertical surfaces of the unloaded bridge as are exposed at an angle between 20° above and 20° below the horizontal or at an angle of 45° from the axis of the bridge.

The resulting loads for the Hell Gate bridge were :

600 lb. per lineal foot of horizontal projection of the top chord;

1 000 lb. per lineal foot of horizontal projection of the bottom chord;

1 500 lb. per lineal foot of floor (inclusive of the 500 lb. moving wind pressure);

Or a total of 3 100 lb. per lineal foot of the bridge.

Adding to this the lateral force of 1 500 lb. due to the train and centrifugal force reactions, the total transversal force is 4 600 lb. per lineal foot of bridge.

Longitudinal forces from traction and braking.— These longitudinal forces have been assumed at 15 000 lb. for each of the eight driving axles of the two locomotives (25 % of the load on each driving axle), or at 1 000 lb. per lineal foot of train (approximately 15 % of the

average weight of the train), whichever gave the greater result being used in the calculations.

This force has been assumed as acting on two tracks only owing to the impracticability of its acting in the same direction at the same time on the four tracks.

Fig. 14. — Assembling of arch bearing.

The general use of air brakes has led to doubts as to whether these forces were the greatest to be expected in service. It has been suggested that a coefficient of impact might even be desirable. In practice the application of the brakes is sufficiently slow to take place without any longitudinal shock.

The friction between wheels and rails varies from 15 tot 30 % of the vertical load on the wheels, but the coefficients used are sufficiently large seeing that the brakes on two trains are not likely to be applied at the same time.

Variation in temperature. — The stresses from temperature have been determined for a variation of $\pm$ 72° F. from the normal temperature of 60° F. The temperature stresses are greatest on the centre panels of the top chord of the arch trusses where they attain values of 4 000 lb. per square inch or about 40 % of the live load stresses.

Total stress. — The *total stress* is obtained by adding :

D = stress due to dead load;
L = stress due to live load;
I = Impact.
Lat = Lateral force and Exc = the so called « excess stress ».

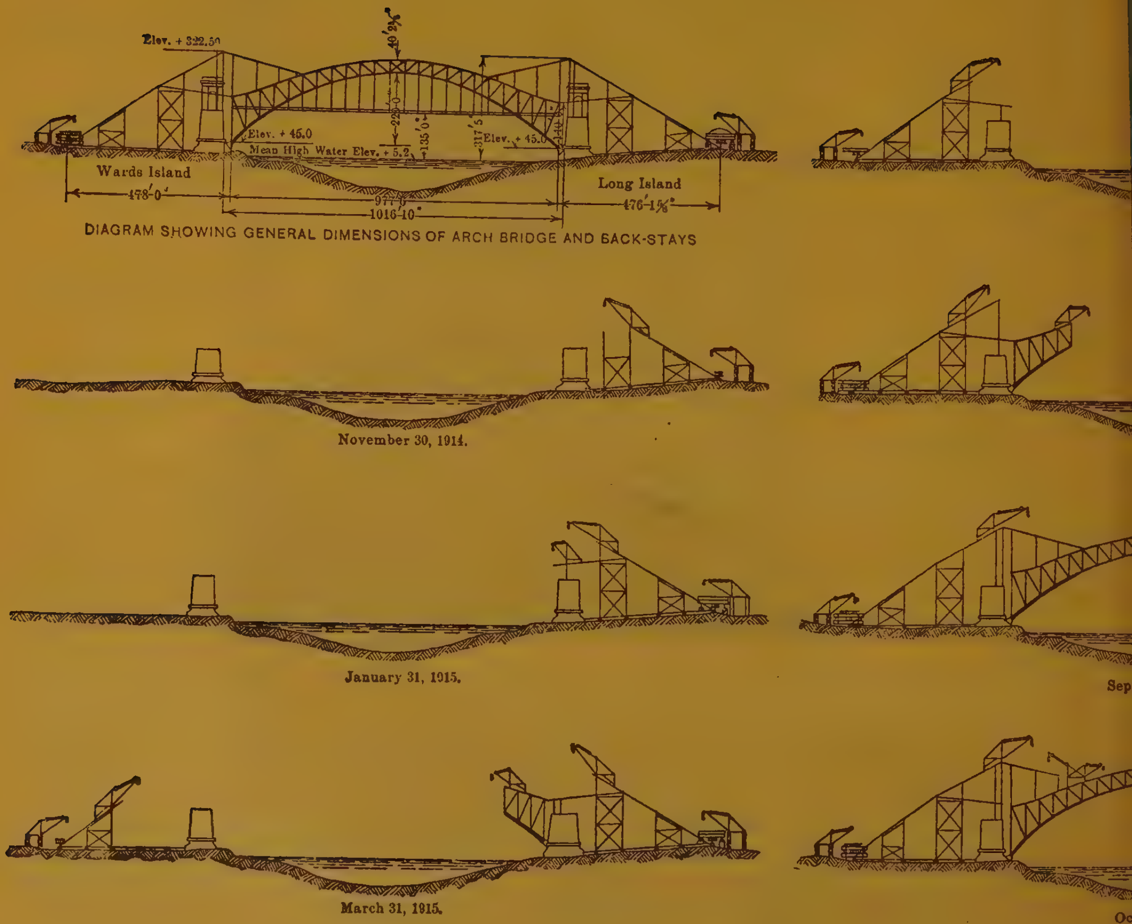
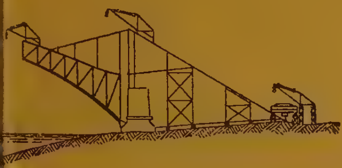

Elev. + 322.50
Elev. + 45.0
Mean High Water Elev. + 5.2
Elev. + 45.0
Wards Island
Long Island
478'-0"
977'-0"
1016'-10"
DIAGRAM SHOWING GENERAL DIMENSIONS OF ARCH BRIDGE AND BACK-STAYS
November 30, 1914.
January 31, 1915.
March 31, 1915.

Fig. 15. — Prog

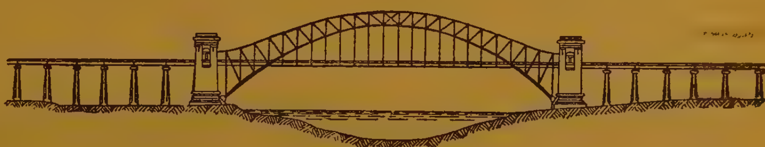
October 31, 1915.



15.

December 31, 1915.

1915.



15.

gram of erection.

This « excess stress » is the sum of the stresses from wind pressure (W), braking force (B), and temperature (I) less 20 % of the sum (D + L + I + Lat). This is equivalent to allowing up to 25 % higher unit stress for the sum (D + L + I + Lat + W + B + T). For members carrying no dead and live load the total stress was made equal to (W + B + T + Lat.).

Permissible unit stresses assumed in pounds per square inch :

Axial tension 24 000

Axial compression :

a) Closed section with diaphragms . . . .
- $\frac{l}{r} = 20$ . . . 24 000
- . . . . .
- $\frac{l}{r} = 120$ . . . 15 000

. . . .

c) Open section with latticing . . . .
- $\frac{l}{r} = 20$ . . . 22 000
- . . . . .
- $\frac{l}{r} = 120$ . . . 12 000

Shearing stresses :

Shop rivets 15 000
Field rivets 12 000

Bearing stress :

Shop rivets 30 000
Field rivets 24 000

Pressure on :

Expansion rollers per lineal inch — diameter in inches × 1 000.
Granite masonry. 800
Concrete 600

The unit stresses in axial tension or compression should be calculated with rivet holes deducted. In compression this assumption is unusual as the rivet is generally supposed to fill the hole perfectly. In practice this is not always the case, especially when the rivet is long. In a large structure such as this one it is more provident to exclude them.

Secondary stresses. — Care was taken when getting out the design to avoid secondary stresses of high value; when necessary to take care of them the size of sections was increased. In the Hell Gate Bridge the maximum secondary stresses which occur simultaneously with the maximum primary stresses are as follows in pounds per square inch :

	Dead load.	*Live load.*	*Combined dead and live load*
Bottom chord	± 1 300	± 1 300	± 2 100
Top chord.	+ 2 100	± 3 100	+ 5 200
	— 2 500	...	— 5 600
Diagonals	± 5 000	± 2 800	± 6 300
Verticals	± 2 200	± 4 400	± 4 800

These, being extreme fibre stresses, can safely be assumed to be covered by the margin of safety of the primary stresses, especially as they occur at points of considerable excess section. Moreover, stress measurements made during and after erection gave lower values than those calculated.

Erection stresses. — The greatest stresses during erection were + 18 600 and — 16 600 lb. per square inch $\left(\frac{l}{r} = 46\right)$ in the arch trusses and + 20 400 and — 19 700 with a wind of 30 lb. per square foot of surface exposed. The erection stresses were all less than the total stresses except in the last panel

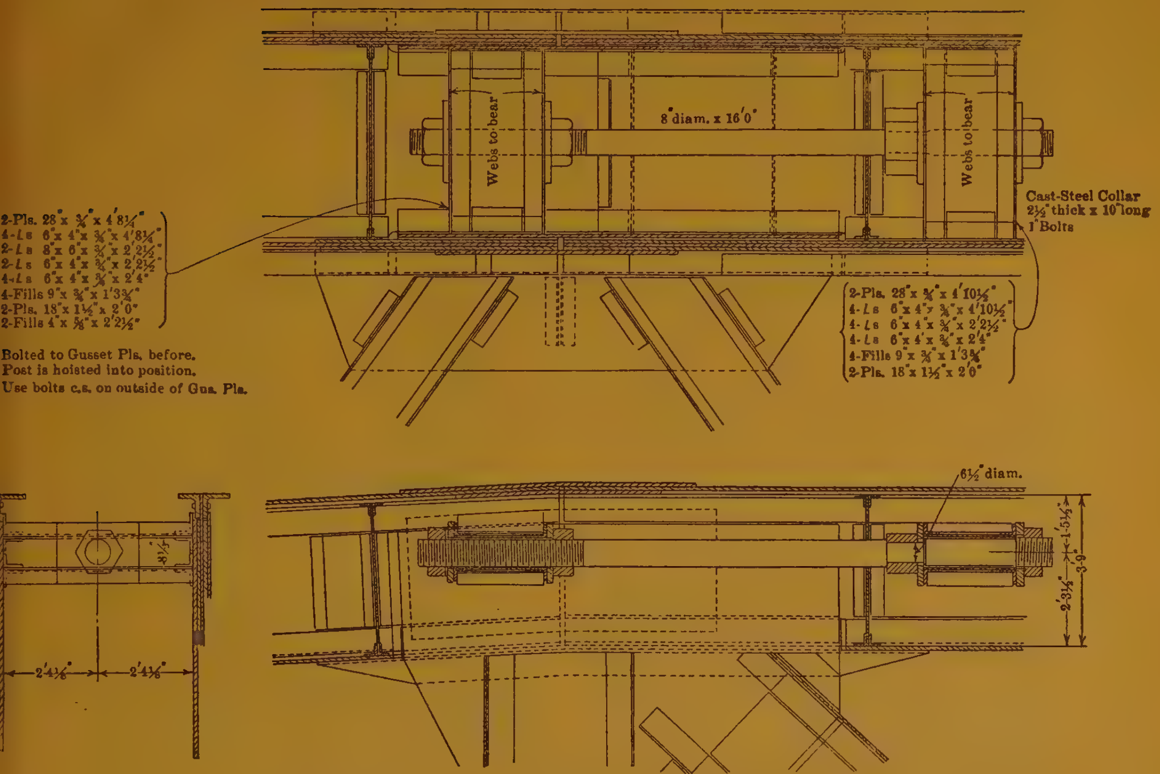


Fig. 16. — Details of adjustment of center top chord.

of the top chord, but the section being greater than the minimum section required, this did not matter.

Erection. — The main trusses were erected on the cantilever principle from the abutments.

Figure 15 shews this method quite clearly. The temporary anchorages were obtained by the temporary use of parts of the permanent bridge approaches.

Particular attention should be given to the method of converting the trusses from three hinged into two hinged arches. (Fig. 16.)

During the temporary position the centre of the top chord and one of the diagonals of the centre panel of each truss were bolted together at one end, but left free to move at the other.

The connection of the free ends (riveting up) had to be made at the normal temperature (60° F.).

The preparatory work took several days so that constant temperature could not be expected. To prevent movement after drilling had been started, the Bridge Company resorted to an ingenious device.

A rod 8 inches in diameter and 16 feet long of sufficient strength to resist any possible tension or compression from changes of temperature was introduced

into each top chord, and secured with double nuts to a diaphragm riveted to the chord.

On a favourable day of normal temperature the nuts were tightened up and the rest of the work was done as planned.

The centre arch of the Hell Gate Bridge is completed by viaduct approaches of ordinary type which will not be described.

Experimental determination of the stresses in the Hell Gate Arch Bridge by direct measurement.

The magnitude of the structure and its interesting constructional features suggested the desirability of measuring the stresses during and after erection. The Hell Gate arch bridge is the largest bridge so far subjected to experimental investigation of this kind.

The instrument used for the stress measurements was a 20-inch strain gauge designed by Mr. James E. Howard.

The lower chords being the most interesting, the observations were chiefly made on them. Figure 17 indicates the location of the gauge points. The large dimensions of the chord sections permitted all the observations to be taken from the inside and facilitated the work.

The observations were taken in accordance with the following programme :

1. Comparison of the measured average stress at the two ends of each member as an index of the precision of the method;

2. Comparison of measured with calculated primary stresses;

3. Comparison of extreme secondary stresses with primary stresses in order to establish empirical relations between the two;

4. Comparison of calculated with measured secondary stresses in order to ascertain the effects of special methods of fabrication and erection on these stresses;

5. Comparison of calculated with measured extreme fibre stresses in order to determine the resultant effect of all variations in primary and secondary stresses.

Comparison of measured and calculated stresses.

The average discrepancy between calculated and measured stress = 5 % of the stress + 200 lb. per square inch. The maximum difference equals 5 % + 1 000 lb. per square inch.

The formulæ for these differences contain both a variable factor depending on the stress and an absolute term, independent thereof and represent the resultant of two groups of errors.

The absolute term (average 200, maximum 1 000 lb. per square inch) represents the inaccuracy of the measurements or the total effect of personal, instrumental and physical errors.

The most important of the physical errors are those due to thermal effects. A variation of 1° F. produces an error of 195 lb. per square inch in the resulting stress. There may be a difference in temperature between the inside and the outside of a large box girder of which one side only is exposed to the sun. The variable factor depending on

the stress can be ascribed to several causes.

Firstly, the variation of the modulus of elasticity from the assumed value of 30 000 000 lb. The variation may be ± 3 %.

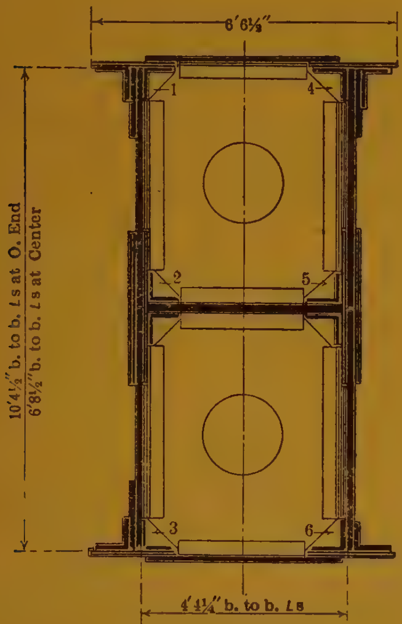


Fig. 17. — Stress measurements. Location of gauge points.

In the assumed loads there is a probable error of ± 3 % and in the cross sections of ± 2 %.

The greater part of the discrepancy of 5 % is due to errors in the calculations and shews the futility of excessive refinement in the calculation of stresses.

Comparison of extreme secondary stresses with primary stresses.

For primary stresses in the ranges 0-1 000, 1 000-2 000, 2 000-3 000, 3 000-5 000, 5 000-7 000 and 7 000-8 000 lb. per square inch the percentages of extreme secondary stress averaged 268, 148, 71, 59, 37, and 32 respectively. This illustrates the diminishing relative importance of secondary stresses with increasing primary stress.

From the observed results can be deduced that the extreme secondary stress in a member = 12 % of the primary force + K, where K varies from 600 to 2 600 with an average value of 1 600 lb. per square inch.

The constant is due to the bending of a member due to its own weight, wind, temperature, etc. The proportional component represents the stress resulting from the primary strains.

Taking into account the conclusion of the preceding paragraph on the difference of 5 % + 1 000 between the observed and calculated stresses and the maximum value 12 % + 2 600 of the secondary stresses, the margin of safety between the elastic limit of the metal and the working stress can be arrived at.

Owing to the special way in which the resulting forces were directed in the lower chord of the Hell Gate Bridge, the secondary stresses were reduced and it would be better to take for these last instead of 12 % of the primary stress, 20 % for most other bridges. Hence, about 25 % + 4 000 should be deducted from the minimum elastic limit to get the safe working stress.

Comparison between calculated and measured secondary stresses.

The average value of calculated secondary stresses for all the bottom chord members and all erection stages is 1 050 lb. per square inch. The average of all measured secondary stresses was only 700 lb. per square inch.

The highest calculated secondary stress in any stage was 2 920 and the corresponding measured stress was 1 990 lb. per square inch. If the secondary stresses are grouped in ranges of percentages, the following comparison is obtained.

In the ranges :

0-20 % 20-40 % 40-100 % 100-300 % and more than 300 %

the average calculated secondary stresses were :

6 % 30 % 69 % 143 % and 473 %

and the corresponding average measured values :

26 % 28 % 46 % 93 % and 110 %.

It will be noted that the difference becomes most important with high secondary stresses.

Comparison of calculated with measured extreme fibre stresses.

The following table gives the results obtained in the lower arch chord members :

Member	0-2	4-6	8-10	12-14	16-18	20-22
	Lb. per square inch.					
Calculated	12 160	12 060	11 770	11 950	12 370	13 270
Measured	11 300	11 650	11 450	11 800	11 950	13 300

The remarkable agreement between the calculated and measured extreme fibre stresses is principally due to the resultants being properly centred through the three faced joints. In an ordinary bridge the measured stresses would have exceeded the calculated stresses.

Summary of Conclusions.

1. — The Howard gauge is well adapted for the measurement of stresses.

2. — The comparison between the calculated and measured primary stresses including errors of observation shew a difference less than 5 %. They are chiefly due to differences in the loads causing the stresses and the differences between the actual and calculated transverse surfaces. They shew that it is unnecessary to carry the calculations too far.

4. — Taking into account the results of observation, maximum difference between calculated and measured stresses :

5 % + 1 000,

maximum difference between extreme fibre stresses :

12 % + 2 600,

and allowing for the fact that the three faced joints in the lower member tend to reduce the secondary stresses, it appears that about 25 % + 4 000 lb. per square inch should be deducted from the minimum elastic limit to get the safe working stress under average conditions.

5. — During erection the secondary stresses — restricted to bending in the plane of the truss — reached a value of 1 050 lb. per square inch calculated and only 700 lb. measured. The maximum calculated secondary stress was 2 920 lb. per square inch and the measured value only 1 990 lb.

Actually the measured secondary stresses were almost always less than those calculated. In the case of the highest values the measured stresses often represented only a small fraction of those calculated.

It is believed that similar results would be found in other structures. The actual secondary stresses will generally

be lower than the calculated values. There is an automatic re-adjustment of strains to reduce them.

7. — The measured stresses have shewn the efficient way the three faced joints of the lower member reduce the extreme fibre stresses.

10. — The stresses in the extreme fibre representing the maximum combined effect of primary and secondary stresses shewed a remarkable agreement with the calculated values, the complete structure working under normal conditions.

As we mentioned above the details in the construction of the *Hell Gate Arch Bridge* are taken from the paper read by Mr. O. H. Ammann, M. Am. Soc. C. E. before the *American Society of Civil Engineers*, and published in volume XLIII, No. 8, Oct. 1917 of their *Proceedings*. The information on the comparison between the calculated and measured stresses is taken from the paper by Mr. D. B. Steinmann Ass. M. Am. Soc. C. E. published in the same number of the *Proceedings* of the Society.

R. Desprets.

[621 .132 .5 (.73)]

Union Pacific Railroad builds largest non-articulated engine.

Figs 1 to 9, pp. 34 to 39.

(From the *Railway Review* and the *Railway Mechanical Engineer.*)

The largest and most powerful non-articulated locomotive constructed thus far — a simple engine capable of hauling Mallet locomotive tonnage over heavy mountain grades at high speeds — was delivered to the Union Pacific Railroad recently by the American Locomotive Company. It also has the distinction of being of an entirely new type, in that it has three simple cylinders and the 4-12-2 wheel arrangement, in addition to many other novel features of construction. This is probably the first successful attempt to use twelve coupled drivers on a locomotive. Moreover, the engine has also the first cast steel cylinders ever applied to a three cylinder engine.

The engine has a firebox 108 1/4 inches wide by 184 1/2 inches in length. The grate surface is 108 1/4 inches by 144 inches, having an area of 108.25 square feet, and the combined heating surface of the firebox, arch tubes and combustion chamber is 591 square feet, which is undoubtedly the largest ever used on a simple locomotive. In fact the entire design is novel in many respects. Furthermore, the engine is capable of developing a tractive force of 96 650 pounds and the factor of adhesion is 3.67. For the foregoing reasons, and because it is the first engine of its type, the Union Pacific has designated the engine as the *Union Pacific type.*

So far the engine represents the most outstanding development in motive power construction for many years. Many factors entered into the selection of a locomotive of this type for heavy fast freight service; the principal consideration being that the Union Pacific desired to improve operating conditions by the use of locomotives capable of hauling heavier trains at higher speeds with lower rates of fuel and water consumption. This road had two principal types of engines for use in heavy fast freight service. One of these was the 2-10-2 type two cylinder locomotive, having a tractive power of 70 450 pounds, and the other was the Mallet compound engine, of the 2-8-8-2 type. The 2-10-2 type locomotives having a traction of 103 000 pounds (running compound) have been the principal source of motive power for fast freight service since 1917, and the Mallet engines were used almost entirely on the mountain maximum grade districts. However, during periods of light traffic, when these engines were no longer urgently needed on the mountain divisions, they were transferred to road service between Green River and Laramie, Wyo., where the maximum grades are 0.8 %. But, due to the fact that the Mallet locomotive is an inherently low speed machine, they could not be operated in this territory during busy periods, as they would block the road. Hence, it was considered advisable to construct a locomotive having the speed characteristics of the 2-10-2 type engines, combined with the greater pulling power of the Mallet locomotives.

As a result of these conclusions preli-

minary investigations were started with a view to designing and building such an engine. About a year ago, due to success of the three cylinder engine on other roads, the Union Pacific decided to purchase a three cylinder locomotive for demonstration and comparison with their 2-10-2 type engines.

This locomotive was constructed as nearly identical with the 2-10-2 type engines as the application of the three cylinder principle would permit. It had the same weight on drivers as the 2-10-2 type engines; the driving wheel diameters were the same, and the proportions of boilers, fireboxes, grate areas, etc., were as nearly alike as it was possible to make them.

Comparative tests conducted between the 2-10-2 type two cylinder engine and the 4-10-2 three cylinder locomotives indicated that the three cylinder engine was capable of hauling 20 % more tonnage in regular service consuming 16 % less fuel for each thousand gross ton-miles.

As a result of these performances the Union Pacific conceived the idea of a locomotive designed for fast freight service which would be capable of hauling the same tonnage as the Mallet engines, but at speeds as high as those attained by the 2-10-2 type engines. In other words it was considered desirable to construct an engine capable of an increase in permissible speed of from twenty to fifty miles an hour, and an increase in average speed over a locomotive division of from twelve to better than twenty miles an hour.

Because of the high tractive power required it was only natural that the possibilities of the articulated type locomotive should be considered first. However, in making the preliminary studies of the design of such an engine as was desired it was found that the construction of the articulated type required a relatively heavy running gear, including two sets of cylinders, pistons, valves, rods, etc., making it almost impossible to provide a boiler of sufficient steam capacity to maintain high tractive power at high speeds, without exceeding the limitations of driving wheel weights.

After further investigation it was decided that the most feasible solution to the problem was offered by the three cylinder locomotive; possibly of the 4-10-2 type. But, in considering this design, the amount of power required, coupled with the permissible weight limit of 59 000 pounds for each driving axle, made necessary the use of six pairs of coupled drivers. Such an arrangement was thought impractical with the two cylinder engine, having the main rods connected to a single driving axle. But, as the three cylinder engine, transmitting its power through two main driving axles, in combination with smaller cylinders, distributes the stresses more equally over the whole frame structure. this type of construction was decided upon. It was found also that this feature of better power distribution, combined with lower dynamic effects, made possible the use of twelve coupled driving wheels, resulting in a design capable of comparatively higher speeds, and increased tractive power. Still another consideration was that with the three cylinder 4-12-2 arrangement the final stresses would be somewhat less than with the 2-10-2 type with outside cylinders of larger dimensions.

The problem of arranging such a long wheel base to permit of the operation of the engine on sixteen degree curves was solved by the installation of lateral motion devices on both the front and rear driving wheels, and by the use of a four wheel leading truck and a two wheel trailing truck, both of the greatest flexibility. The engine was built with flanged driving tires on all wheels, except the fourth pair, but it has been determined, based on actual operation, that future locomotives of this type are

Fig. 1. — Three-cylinder Union Pacific type locomotive No. 9000, built by the American Locomotive Company.

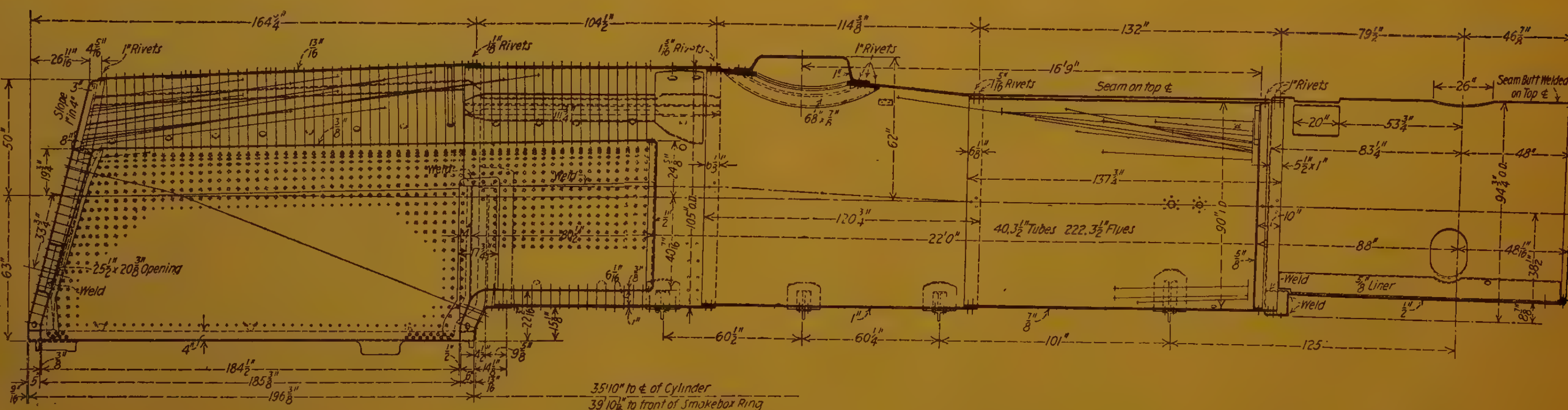


Fig. 2. — Sectional elevation of the boiler of the Union Pacific type locomotive No. 9000.

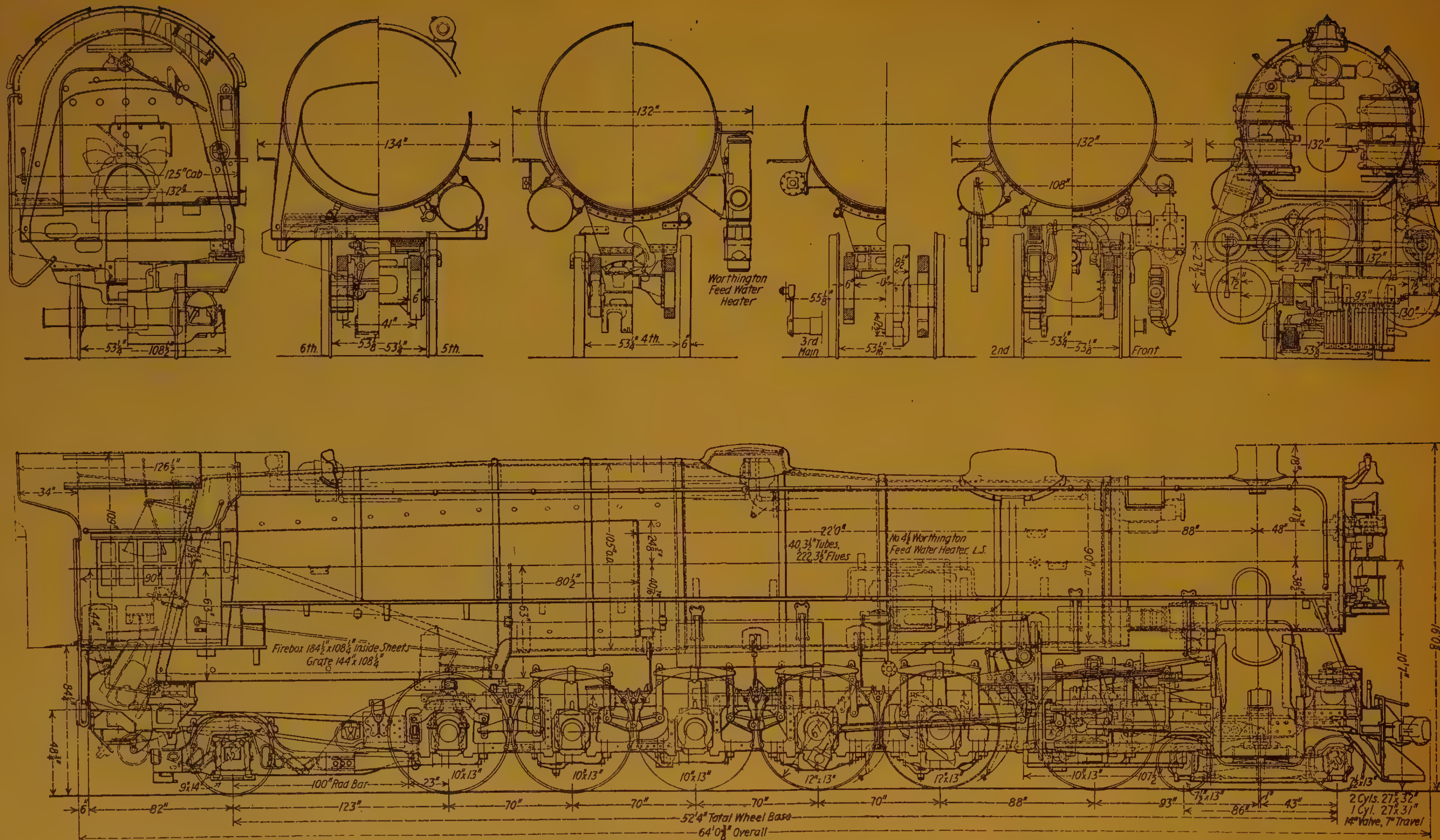


Fig. 3. — Elevation and cross section drawings of the Union Pacific type locomotive No. 9000.

to be fitted with flanged tires on all drivers.

Another problem of considerable magnitude was that of providing a boiler of sufficient capacity to accommodate cylinder requirements. Limited in weight to 59 000 pounds on each driving axle it was desired to provide a boiler of maximum capacity and yet keep the total weight of the engine as low as possible. The first consideration was to obtain a firebox to burn semi-bituminous coal. To do this it was necessary to provide firebox volume combined with length of flameway and depth. Both flameway and volume were secured by a combination of Gaines wall and internal combustion chamber. On many other types of engines using the Gaines wall there was not sufficient depth from the crown sheet to the top of the grates, but a satisfactory depth was obtained in this case by arranging the rear drivers in such a manner that they protrude into the firebox space, between the throat sheet and the front of the Gaines wall. Another consideration in connection with the construction of the boiler for this engine was that of using tubes of the same length as were standard in the boilers of other Union Pacific engines, which are 22 feet and which had been found to be of about the longest effective length. While seemingly this gave a rather short tube length for a boiler of this size, the long distance from the front tube sheet to the center of the cylinders should improve draft conditions, by a more equal distribution of the draft on the upper and lower flues.

This engine has a boiler of the extended wagon top type, 90 inches inside diameter at the first course, and 105 inches outside diameter at the third course. It has a total evaporative surface of 5 853 square feet and a superheating surface of 2 560 square feet. Additional boiler capacity was obtained by the use of the type E superheater and a Worthington feed water heater of 10 000 gallon capacity. Other interesting boiler proportions are shown in the following table of ratios :

Grate area to cylinder volume.	3.44
Furnace volume to grate area	8.80
Heating surface to cylinder volume . .	267.00
Heating surface to grate area	77.70
Total weight to heating surface. . . .	58.80
Firebox heating surface to total heating surface	0.063
Total heating surface to tube heating surface	1.11
Total heating surface to superheating surface	2.28

As has been stated previously the cylinders are of cast steel. The two outside cylinders are 27 inches in diameter with a stroke of 32 inches and the inside cylinder has a diameter of 27 inches with a stroke of 31 inches. The steam pipe inlet on the right side, which supplies steam to both the right and the inside cylinder, is arranged so as to deflect any water in the steam into the right cylinder, from which it can be drained more easily. The piston valve is of the single ported type having eight rings, double the number used ordinarily, which is standard practice on the Union Pacific.

The valves are operated by Walschaerts valve gear. They have a maximum travel of 7 inches, an outside lap of 1 1/4 inches, an exhaust clearance of 1/16 inch and a lead in full gear of 3/16 inch. The valve of the inside cylinder is operated by a modified form of Gresley valve motion using transverse levers which has been adopted by the American Locomotive Company as standard on three cylinder engines.

All of the piston rods, valve motion, driving rods, axles and crank pins are of carbon vanadium steel. The driving boxes are of cast steel fitted with Franklin adjustable wedges. On the main and crank axle driving boxes supplemental bearings are used. These bearings extend well below the center line of the axle for the purpose of reducing

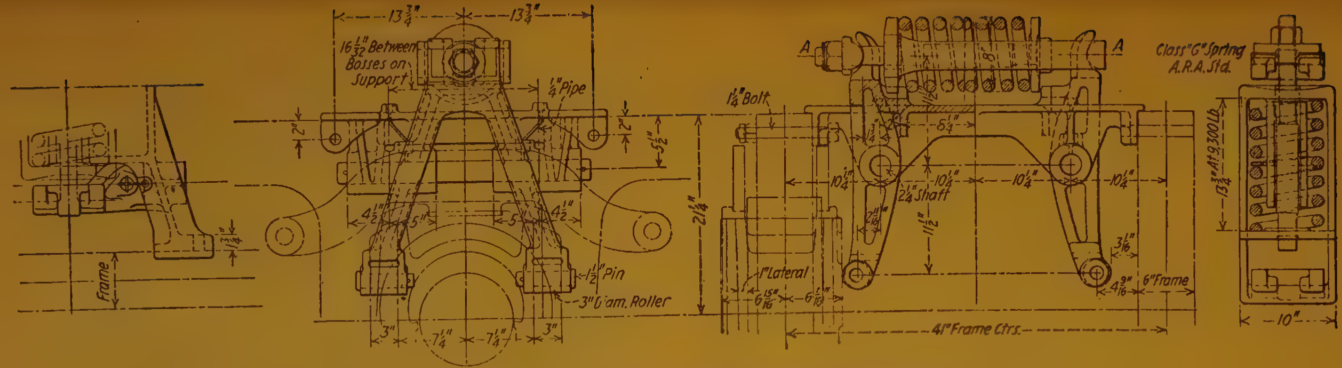


Fig. 4. — The lateral motion device applied to the front and rear axles.

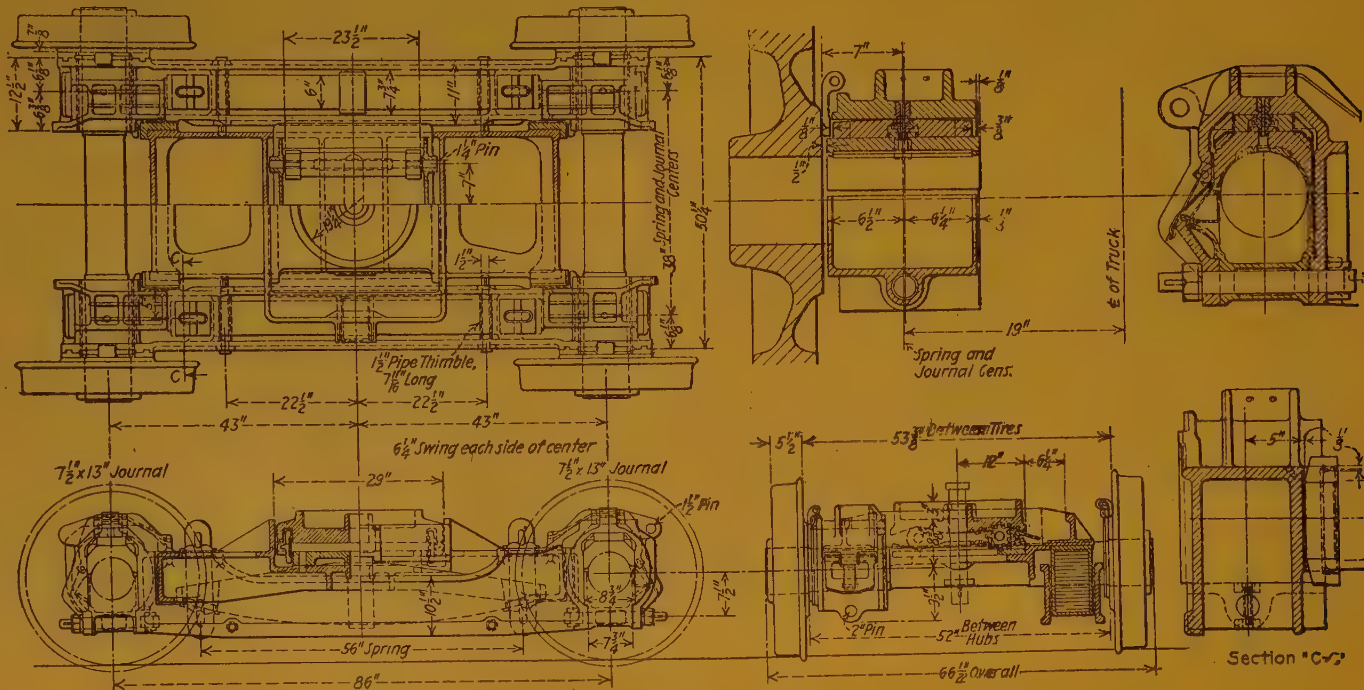


Fig. 5. — The engine truck details.

wear on the journals. When this type of driving box is employed on the crank axle the grease lubricant must be applied from the bottom. For this reason the cellars are fitted with drop bottoms and the pedestal crossties or binders are arched down in the center to allow of easy renewal of the grease cakes. These cellars also form spreaders in the driving boxes to prevent the sides from closing.

Another novel feature of this engine is the engine truck. It is of such construction as to eliminate practically all bolted fastenings. The frame is made up of three principal castings; two journal box castings and a frame, each of simple construction. The truck is equalized perfectly without the use of the ordinary types of equalizers; the usual pedestal wearing surfaces are eliminated; the journal box castings provide hinged lids at the outside of each journal as an aid in lubricating the bearings without removing the cellars, and the construction permits of the use of very long flexible easy riding springs. Furthermore, the use of racks and geared rollers makes the truck of the constant resistance type. The journal bearings rest on adjustable wedges similar to those used on tender trucks, thus insuring a perfectly aligned journal bearing pressure over the entire surface. This engine truck has 7 1/2-inch by 13-inch journals and 30-inch diameter Edgewater rolled steel wheels.

The engine truck is also fitted with hub liners of novel design. These are made in two halves, each half sliding down from the top into inwardly sloping dovetailed grooves; so that when in place one bolt serves to hold them securely in position. By removing this bolt the two halves of the hub liners may be removed, rebabbitted to the required thickness and reapplied without dismantling or removing the truck from the engine, or without disturbing any part of the locomotive. Oil cavities are cast in the top half of each liner for lubricating the hub surfaces. These liners have been used on engine trucks for a period of two years. Their construction is such as to provide for quick renewals for repairs, thus reducing the standby losses in adjusting lateral.

The driving wheels are 67 inches in diameter. A 63-inch wheel is generally considered standard on heavy engines for freight service, but in this particular case it was found that a satisfactory crank axle design required the use of a 67-inch wheel, which in turn improved the whole design for the work intended.

The trailing truck is of the Commonwealth Steel Company Delta type having 9-inch by 14-inch journals and 45-inch diameter wheels.

The lateral motion devices applied to the front and back drivers are adjustable to suit speed and curvature requirements, the resistance increasing with the amount of lateral displacement. The device imposes no excess load on the driving springs, and uses an ordinary class C car spring. The rollers bearing against the inner surfaces of the driving boxes are free when the boxes are in normal position in the frame, and are therefore easy to replace.

The total overall length of the engine and tender, over the couplers, is 102 ft. 6 5/8 in. Its maximum height is 16 ft. 1 1/2 in., over the dome and the extreme width is 11 ft. 2 in. over running boards. The total combined weight of the engine and tender in operating condition is 782 000 pounds. This is so distributed that the tender weight is 287 000 pounds and that of the engine alone 495 000 pounds. The weight of the engine is divided in such a manner that 80 000 pounds is carried on the leading truck — 40 000 pounds on each of the two axles — 60 000 pounds on the trailing truck, and 355 000 pounds on the driving wheels. The driving wheel load is distributed over the six coupled axles so

Fig. 6. — Rear view of the cast steel cylinders as assembled on the engine truck.

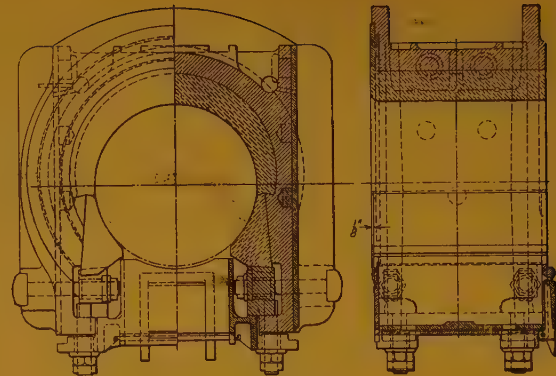


Fig. 7. — Design of driving box used on the main and crank axles.

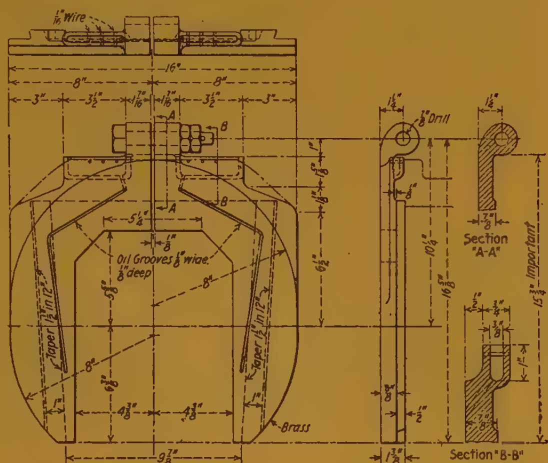


Fig. 8. — Details of the engine truck hub liners.

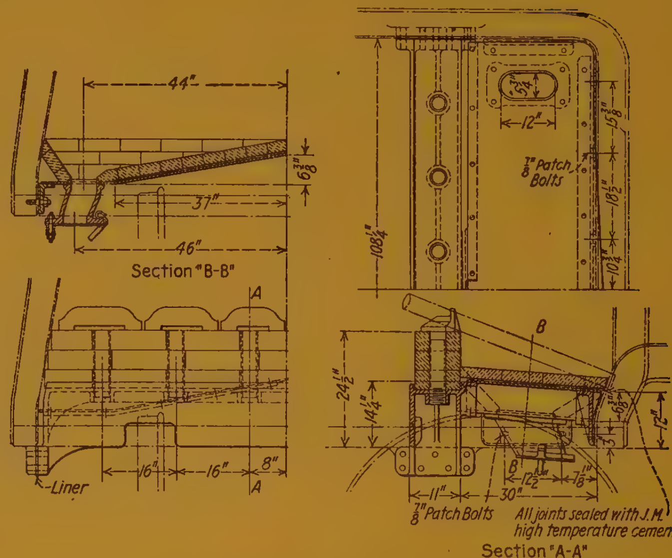


Fig. 9. — Arrangement of the Gaines wall in the firebox.

that each axle has an approximate average load of slightly more than 59 000 pounds.

The engine has a total wheel base of 52 ft. 4 in. and the driving wheel base is 30 ft. 8 in., of which 17 ft. 6 in. is rigid, the total wheel base of engine and tender being 91 ft. 6 1/2 in. The tender is of the Vanderbilt type supported on six wheel trucks and a cast steel underframe. It has a capacity for 15 000 gallons of water and 21 tons of coal. Other weights and dimensions are shown in the accompanying table.

Among the appliances used on the engine, aside from those mentioned, are the Elvin stoker, New York air brakes and signal equipment, and New York air compressors. The latter are carried on the smoke box front, as the feed water heater pump occupies the usual space where the air pumps were carried formerly on the left side of the boiler.

Principal weights, dimensions and proportions of Union Pacific Railroad Overland 4-10-2 type and Union Pacific 4-12-2 type three cylinder locomotives numbers 8 000 and 9 000 respectively :

Type	4-10-2	4-12-2
Service	Freight.	Freight.
Fuel	Bituminous coal.	Bituminous coal.
Builder	American.	American.
Cylinders, three, diameter and stroke :		
Inside, one cylinder	25 inches by 28 inches.	27 inches by 31 inches.
Outside, two cylinders	25 inches by 30 inches.	27 inches by 32 inches.
Valves, piston, diameter.	11 inches.	14 inches.
Maximum travel	6 1/4 inches.	7 inches.
Lead in full gear	3/16 inch.	3/16 inch.
Steam lap	1 1/8 inches.	1 1/4 inches.
Exhaust clearance	0 inch.	1/16 inch.
Weights in working order :		
On leading truck	60 000 lb.	80 000 lb.
On driving wheels	288 500 lb.	355 000 lb.
On trailing truck	56 500 lb.	60 000 lb.
Total engine	405 000 lb.	495 000 lb.
Tender	242 100 lb.	287 000 lb.
Total engine and tender	647 000 lb.	782 000 lb.
Tractive power, estimated	78 000 lb.	96 650 lb.
Factor of adhesion	3.7	3.67
Wheel bases :		
Driving	22 ft. 6 in.	30 ft. 8 in.
Rigid	16 ft. 6 in.	17 ft. 6 in.
Engine	44 ft. 1 in.	52 ft. 4 in.
Engine and tender	82 ft. 5 in.	91 ft. 6 1/2 in.
Wheels, diameter :		
Leading truck	30 inches.	30 inches.
Driving	63 inches.	67 inches.
Trailing	45 inches.	45 inches.

Journals, diameter and length :		
Leading truck	6 1/2 inches by 12 inches.	7 1/2 inches by 13 inches.
Driving, main	11 inches by 12 inches.	12 inches by 13 inches.
Driving, others	10 inches by 12 inches.	10 inches by 13 inches.
Trailing truck	9 inches by 14 inches.	9 inches by 14 inches.
Boilers :		
Type	Inverted wagon top.	Inverted wagon top.
Working pressure	210 lb.	220 lb.
Diameter first course	86 1/4 inches.	90 inches.
Firebox :		
Length	126 inches.	184 1/2 inches.
Width	96 inches.	108 1/4 inches.
Grate area	84 square feet.	108.25 square feet.
Combustion chamber length	60 1/4 inches.	80 1/2 inches.
Tubes :		
Number and diameter	250 — 2 1/4 inches.	40 — 3 1/2 inches.
Length	23 ft. 6 in.	22 feet.
Flues :		
Number and diameter	50 — 5 1/2 inches.	222 — 3 1/2 inches.
Length	23 ft. 6 in.	22 feet.
Spacing tubes and flues	13/16 inch.	11/16 inch.
Arch tubes, number and diameter	4 — 3 inches.	5 — 3 1/2 inches.
Heating surfaces :		
Firebox and combustion chamber	357 square feet.	529 square feet.
Tubes	3 447 — —	803 — —
Flues	1 685 — —	4 459 — —
Arch tubes	32 — —	62 — —
Total	5 521 — —	5 853 — —
Superheating	1 375 — —	2 560 — —
Comb. evaporating and superheating	6 896 — —	8 413 — —
Tender :		
Type	Cylindrical.	Cylindrical.
Trucks	6-wheel.	6-wheel.
Capacity, fuel	20 tons.	21 tons.
Capacity, water	12 000 gallons.	15 000 gallons.
Wheels, diameter	33 inches.	33 inches.
Journals, diameter and length	6 inches by 11 inches.	6 inches by 11 inches.

[656 .253 (.42)]

Four aspect colour light signals and the phenomena connected with colour light signals. (1)

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Figs. 1 to 4, pp. 44 to 49.

With the view of simplifying the signals as far as the drivers and motormen are concerned, and to add to the efficiency of the signals as regards the greater capacity of the running lines, the Institution has taken a great interest in the four aspect colour light system of signalling, and as you are aware, appointed a Committee whose report has been circulated to all members. A system of four aspect colour light signals similar to that recommended by your Committee is about to be introduced on the Southern Railway. When such recommendations are acted upon it is very generally found some modifications are required. There is nothing like practice to develop a system, or to find that it does not meet requirements at all, and then the system is discarded. In this case of the four aspect colour signals, their use appears to meet the requirements, but the conditions met with in practice in running, calls for some alterations and additions. I propose to deal with these and to call your attention to some of the phenoma of colour lights used in light signals and to repeat here some of the experiments I have made in meeting the conditions that practice demands.

First, the four aspect colour light system of signalling uses three colours, green for « clear », yellow for « caution », and « warning », and « red » for « stop », so that in each case an ordinary person cannot be confused.

The four aspects in the colour light system we are adopting are :

Green.	Clear.
Double yellow. . .	Warning.
Single yellow . . .	Caution.
Red	Stop.

A green aspect will tell a driver going at any speed, say 70 miles per hour, that he has a clear road and that the next signal ahead at that moment is either a double yellow or a green, and he will be sure to find one of the two when he reaches it, except under emergency conditions, when of course any signal may be exhibited.

A driver passing a double yellow aspect receives a warning that he has full braking distance and that the next signal ahead is at that moment in the « caution » condition, *i. e.*, exhibiting a single yellow aspect; under such conditions the driver will take steps to get his train under control.

The single yellow aspect cautions the driver that at that moment the next signal ahead is in the « stop » condition and he must be prepared to stop at that signal.

It is so that the signal aspect exhibited at any one time depends upon the condition of the road ahead so that although an aspect may be red representing

(1) Paper read before the Institution of Railway Signal Engineers, on 10 March 1926.

« stop » at the time, a driver passes a single yellow, when he arrives at the signal aspect ahead it may have changed to single yellow, double yellow, or even green owing to the conditions of the road ahead having altered. This is the case with any system of signals, in fact the signals ahead of a train may be said to always be in a state of flux, depending upon the state of the road ahead.

But on the other hand a driver always comes to a double yellow and a single yellow before he reaches a red or « stop » aspect. He may of course pass several double yellow or single yellow aspects in succession, but in any case before he arrives at an aspect exhibiting red or « stop » he will have passed a double yellow and a single yellow aspect.

In effect the double yellow aspect is the signal for « warning » the driver going at 70 miles per hour and the single yellow aspect for the driver or motorman travelling about 30 to 40 miles per hour.

The system is designed and I think will allow of the trains being run at the maximum speed allowable under the conditions applying on the lines where the system is introduced and thus the lines are filled to their maximum capacity.

One of the problems that arises is how to deal with junctions and diverging lines. For myself, I strongly advocate one four aspect colour light signal and a route indicator in every case. It is simpler and if adopted would be uniform and the number of lights exhibited less, which all tends to economy and in my opinion, efficiency. But the objection raised is that the driver cannot see the route indicator so clearly as he can the coloured aspect itself, or in other words, he can see the coloured aspect further away than he can see and read the route indicator; that may be so, but it would appear that so long as a driver can see the route set up for him to run over for say 150 to 200 yards before he reaches the junction, that should be sufficient. However, to meet the drivers' objections it has been arranged that at slow speed diverging junctions such as the starting signal from a platform, or at a home signal for entering a station, where there are two or more diverging routes, one four aspect colour light signal and a route indicator shall be used. In the cases of diverging junctions where trains run at speed, a four aspect signal shall be provided for each route.

If one four aspect coloured signal and a route indicator is used, the driver is not called upon to pass a red light, but in the cases where two or more four aspect colour light signals are installed side by side, at a diverging junction, he of course has to pass one or more red lights which apply to the road he is travelling on, but they do not of course refer to the route over which he is travelling, but in the multiplicity of aspects on the same post there is a possibility of a misunderstanding of the signal aspects which is absent in the case of a single four aspect colour signal plus a route indicator.

It is proposed to use a daylight route indicator, the brilliancy of the light from which will be equivalent to that of the running aspects with about six or seven-inch letters or figure as required on an eight-inch lens. The description of the route indicator will be given in the second part of the paper.

It has often been necessary in the past, owing to the curvature of the line or other reasons, to provide repeaters of the signals the driver may be approaching, and which he cannot see in time to act upon them, thus time will be lost in consequence. If the signal is « on » the repeater as a matter of course shows « on » also, and the driver has to pass that « stop » or red light.

It may be said that the shape of the arm, or size of the light is different to the ordinary signal, but at night time the

Fig. 1. — Colour light signals.

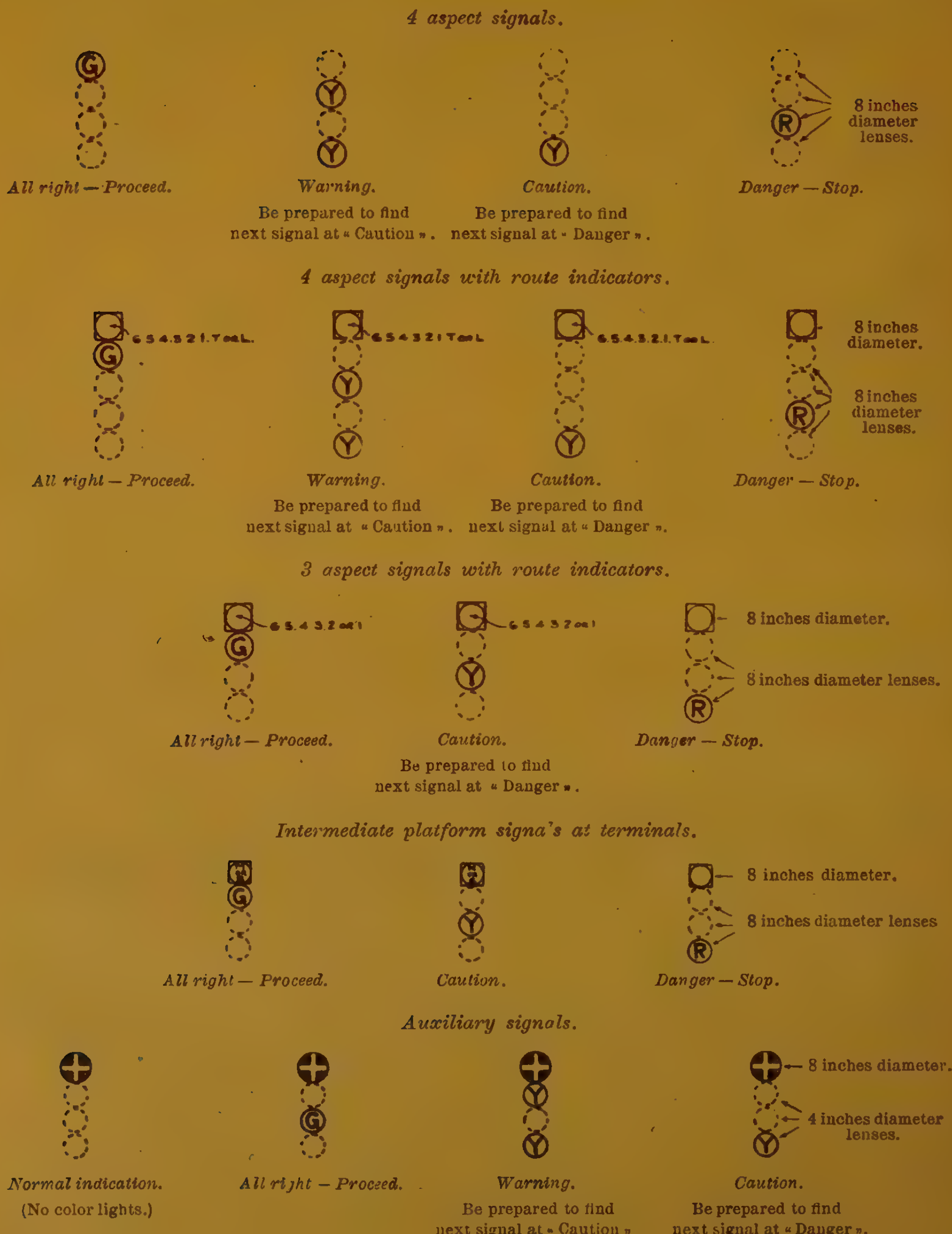


Fig. 1. — Colour light signals. (*Continued.*)

Shunting signals.

Proceed. *Normal indication.*

Auxiliary signals for foggy weather to be switched in by signalman.

Normal. (No color lights.)

All right — Proceed.

Warning. Be prepared to find next signal at « Caution ».

Caution. Be prepared to find next signal at « Danger ».

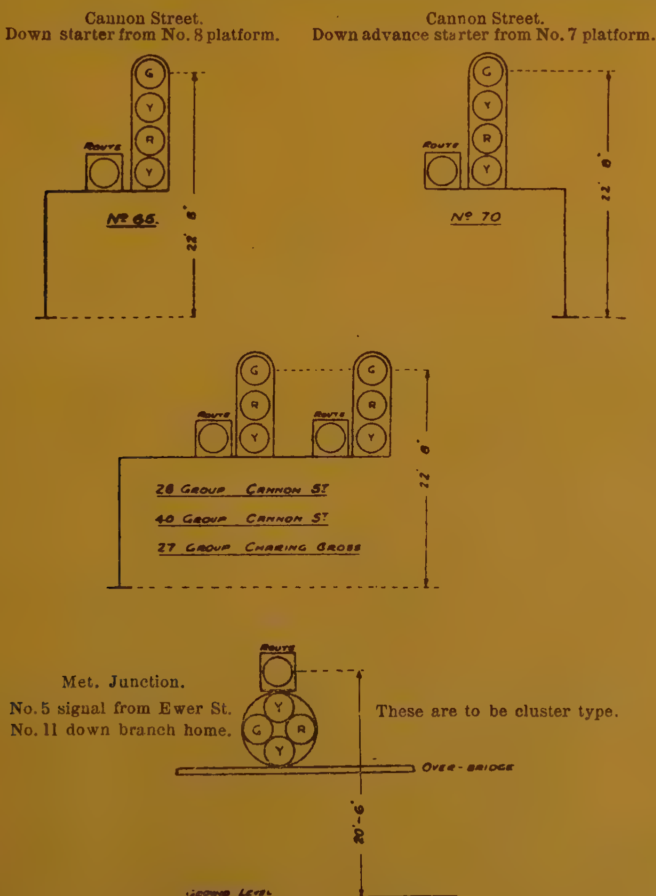


Fig. 2. — Special arrangement of signals at Cannon Street, Charing Cross & Met. Junction owing to insufficient clearance.

driver has to pass a red light, which as I explained above, has been avoided as far as the running traffic is concerned, and the four aspect colour light system has been designed so that a red light for the road ahead on all occasions shall be an absolute « stop » signal. In order to comply with that stipulation a repeater of a signal ahead cannot be used. This difficulty has been overcome by providing an auxiliary signal instead of a repeater in such cases as are in question, namely, where a driver cannot get a view of the signal he is approaching in time. It has been arranged that the auxiliary signal shall show three aspects : green, double yellow and single yellow, and have a white light (St. George's cross) brilliantly illuminated on a black background immediately above the colour light aspects as shown in figure 1. Normally the auxiliary signal would show the white cross only to avoid any risk of the aspect, if it were provided, conflicting with the signal behind.

For instance, if a train were standing at a starting signal, which was in the « on » or red condition, the auxiliary signal would exhibit the St. George's cross only. When the starting signal exhibited a *single yellow* and the train had passed the starting signal and the engine reached the first track circuit past the starting signal, in the case of a straight road, or the first common track circuit where there were a number of platform roads converging on to the main running road, the auxiliary signal would change to the St. George's cross with a *single yellow* underneath.

If the signal ahead was showing a *single yellow* the auxiliary would show *double yellow*. If *double yellow* or *green* was exhibited in the signal ahead the auxiliary signal would show *green* with the St. George's cross above it.

A train would however never approach an auxiliary signal in the normal condition as it would have been set to the correct aspect immediately the train passed the signal behind. It is however thought that the number of these auxiliary signals required will be small owing to the fact that a driver will in all cases have at least two warnings or a warning and a caution, before arriving at a « stop » signal.

It will be seen that the aspect of this auxiliary signal exhibited is in reality equivalent to the aspect that would be exhibited at the signal in the rear had the approaching train not been in the section. Take the case of a driver who has passed a single yellow aspect. He is running under instructions to be prepared to stop at the next signal, which is in the red or « stop » condition. When he reaches the auxiliary signal, supposing the condition of the road ahead has not changed, then the aspect exhibited at the auxiliary signal will be single yellow with the white cross above, giving him the same instructions. Had the signal ahead changed from red to single yellow, then the auxiliary signal aspect would also change to double yellow with white cross above it. Had the signal ahead changed to double yellow or green then the auxiliary signal would exhibit a green light and in both cases the instruction is the same as with the ordinary running signal aspect. The lens upon which the brilliant white St. George's cross is exhibited is 8 inches in diameter, but the colour light lenses are only 4 inches in diameter so as to make a further distinction between them and the running signals.

It is hoped, almost anticipated from experiments that I have made and will describe later, that fog repeaters of the signal ahead will not be required, but in case they are wanted it has been arranged to use a three aspect colour auxiliary signal with the letter « F » brilliantly illuminated on a black background instead of the St. George's cross, These, if used, will be controlled by the signalman from the signal box.

Shunt signals will have lenses 2 inches in diameter and be two aspect light signals, either red and green. The green will probably be a brilliantly illuminated green « S » on a black background, the letter « S » being 1 3/4 inches on a 2-inch lens.

Generally, the aspects will be arranged in a vertical line, but in many places there is not sufficient head room to allow of this, and in such cases the four aspect lights have been arranged in the form of a cross in a cluster, the green being on the left-hand side, the red on the right and nearest to the driver, and the two yellow aspects, one on the top and the other at the bottom, so that they appear in the same vertical line and separated sufficiently to prevent them combining or running into each other at a distance. Thus the general form of the aspects is maintained as far as the driver is concerned. See figure 2.

In some cases where signals have had to be placed under station roofs, there has not been sufficient headway to allow of the route indicator and coloured aspects to be in a vertical line; in those cases it has been arranged to place the route indicator or St. George's cross on the left hand side of the coloured aspects. See figures 2 and 4.

Owing to the fact that the light given out from the front of the lens of the colour light aspect signal lamps is in the form of a beam, it can only be seen, as I will show later, whilst the driver is in a straight line, or very nearly so, with the front of the lens, consequently if the lamp is fixed high up the post when he arrives within about 15 to 40 feet he cannot see the beam, in fact he is below the beam, but with light signals it is arranged that the lamps shall be as near to the driver's line of sight as possible; 11-ft. 6-in. above rail level is the height aimed at. The lamps have perforce to be placed to the left of the line at least 4-ft. 6-in. from the running rail so that even then when he comes up to the signal post, as he is entitled to do, he is out of the main beam of light and could not see this main beam. To overcome this, a side light has to be provided (there are several ways of doing this). A sample of that to be used on the Southern Railway is on the table, I will describe it later.

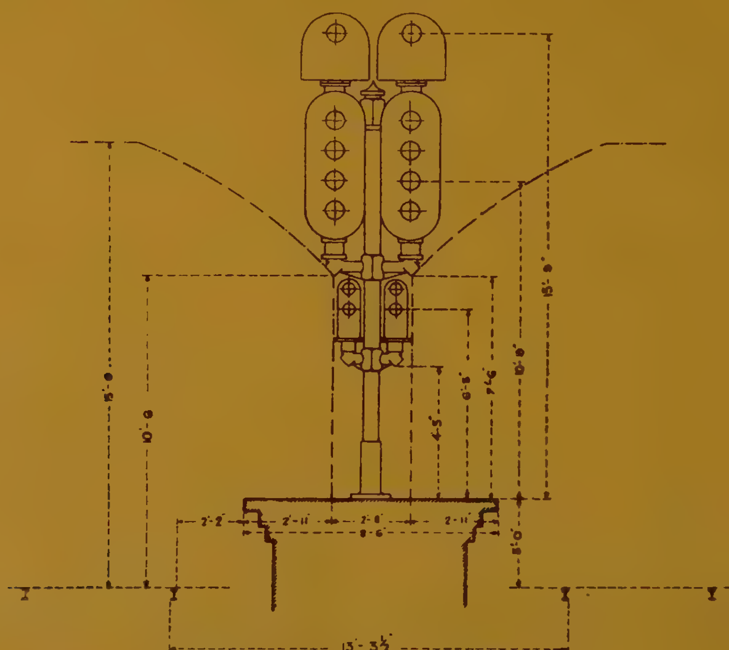
The amount of light in a beam from a lens is a maximum when the source of light is in the focus of the lens. It therefore follows that for a lamp to be at maximum efficiency it should be arranged that the source of light is in the focus of the lens and any adjustment of the light beam for the purpose of directional sighting should be done by adjusting the lamp as a whole. Although the main beam can be moved to another direction by shifting the source of light from the focus, it is only done at the expense of the efficiency of the lamp itself.

The lamp should be as simple and as free from adjusting gadgets as possible. In a great many cases these focussing devices can only be used once, that is, when the lamp is first installed. In any case they can seldom be used after erection, owing to the awkward conditions at the places where, often, they have to be fixed. Further, the apparatus to enable very fine adjustments to be made is very expensive, and if you adjust the direction of the beam by altering the source of light from the focal point you have afterwards to close the door of the lamp and then you cannot be sure, after this is done, that you have not moved the lamp bodily and thus displaced the beam out of the direction you wish it to point.

The posts on which the light aspects are erected should be rigid; if this is not done the beams of light will vibrate with wind pressure, or other causes, and a very small swing of the lamps themselves will mean a big deflection at a distance of half a mile. For instance, if the lamp case were deflected one de-

gree then the beam at a position 800 yards away would be 15.8 yards from its normal position. This would be of importance especially at places where a group of signal aspects were exhibited.

The signal aspects for the straight running lines present no difficulty as the aspects are in one vertical line, but at diverging junctions two separate sets of light signals are placed side by side vertically as seen in figure 3. The aspects for the straight road are similarly arranged to those on a single straight road, but when the route is set for the diverging line, such as in the case of a crossover from say the up main through to up main local line, it is arranged that the driver shall pass a single yellow aspect in the signal next before the junction signal and that the junction signal shall remain at « on » or red, irrespective of the state of the road ahead, until



Signals 1 and 2, *5 ft. 0 in. from top of ramp.*
Signals 3 and 4, *10 ft. 0 in. from top of ramp.*

Fig. 3. — Cannon Street platforms 1-2 and 3-4 starting signals.

the driver has passed the single yellow aspect; as it is thought that although the driver should receive a caution signal on approaching the junction and pass a single yellow aspect, a green, double yellow or single yellow aspect should not be exhibited in the junction signal at the same time, as it is undesirable that a driver should be given a single yellow aspect as a « caution » on account of the crossing he is approaching and at the same time see a green, single or double yellow showing the road ahead of the junction is « clear », it would not be in conformity with the sequence adopted with the four aspect colour signal scheme. This modification should not, provided the junctions are not nu-

merous, delay traffic unduly, but at terminal stations and other similar places it is considered that the speed of trains is slow and the principle of this modification is not applied within the station limits.

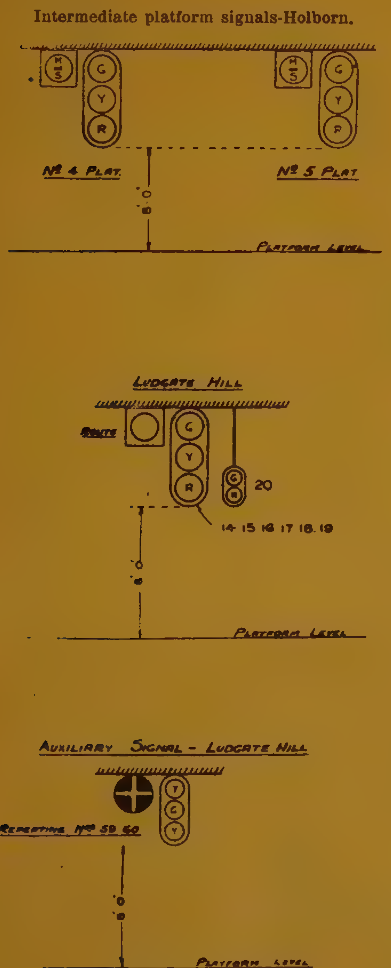


Fig. 4. — Special arrangement of signals at Holborn & Ludgate Hill — owing to insufficient clearance.

It is so that the shapes of all lenses are designed on the understanding that the light will be placed at the focus of the lens, but the focus of a lens is a point and it is impossible to get an electric incandescent lamp in which the source of light is at a point, although in many such lamps there is a concentration of many candle power in a very small area, but still it is not a point, consequently the rays of light in the beam are not parallel and you get a spread of the light; this is very important when you want to exhibit brilliantly illuminated figures or letters.

The efficient life of the lamps is of great importance, as to a large degree the cost of maintenance depends upon it. This of course depends upon the quality of the lamps, the position of the filaments when burning, whether they are placed in the sockets with the filaments lying horizontal, upwards vertical, or downwards vertical. If the filament, which is often made up of two parts in the form of an inverted V, is arranged with the apex pointing upwards, the two sides are apt to sag, and the two sides then touch each other at some point just below the apex, with the consequence that a part of the filament is short circuited the current increases to a dangerous amount and the lamp burns out, whereas, had the filament been arranged with the apex of the V downwards this would not be so likely to happen.

Lamps have been burnt for 1 700 hours before burning out, but it is of great importance that lamps should not burn out in practice as it is necessary that the light aspect should show continuously. In a normal « danger » signalling system the red aspect is exhibited very much longer than the yellow or green aspects, consequently the lamp in the red aspect is likely to burn out more often than those of the other aspects. I have arranged that after a lamp has burnt 850 hours in the red aspect lamp, that the lamp shall be changed whether it has spent its useful life or not. But for

economy and efficiency I have arranged that these, what may be called partly spent lamps, shall be used in the other three aspects as required. This method, which may be modified if found necessary, appears to provide that an electric incandescent lamp will never in practice actually burn out, so that the aspect will always be exhibited to the driver when wanted.

In America, coloured glasses for the different colours in use, green, yellow, red, were standardised, but it was thought that the manufacturers could not work absolutely to one shade of yellow or green or red and a tolerance was agreed upon that the colour of the yellow glasses should be between what was called the dark yellow and the light yellow limits, similarly with red and green.

In the case of the yellow, after a considerable amount of investigation at the national physical laboratory and other places, a similar light and dark limit was agreed upon, the idea being that if the yellow glasses or lenses fell between those limits the yellow colour given out would be very near the mean of the two standards.

But the light given out by the signal lamp does not depend alone upon the colour of the signal spectacle glass or colour of the lens, but upon the colour source of light also, in other words the temperature of the illuminant.

When I saw two yellow lenses side by side together or one after the other, the dark and then the light limits, I have no hesitation in saying that the dark limit yellow could very easily have been mistaken for red and it was immediately obvious that the yellow aspects must all be of the same hue. The standard adopted on the Southern Railway is that yellow when an electric incandescent light is the source of the light, gives the standard yellow aspect or a wave length of 0.597 μ.

The diameters of the lenses in the various aspects are as follows :

For running signal aspects.	8 inches.
Route indicators . . .	8 —
Auxiliary signal aspects :	
For running signal aspects.	8 inches.
The fog aspect « F ».	8 —
The colour aspect. .	4 —
Shunt signals	2 —

Figures 1, 2 and 3 show the aspects of the four aspect light signals as they will appear in practice on the Southern Railway.

The question as to what should be done as regards signals at the junction of the existing semaphore arm and the new four aspect light signal system, *i. e.*, where shall one begin and the other finish. This question has been solved by arranging that the starting signal at Elephant and Castle, where the semaphore system ends, shall be of the semaphore arm pattern, but the equivalent of the distant signal for Blackfriars signal box shall be a two aspect light signal with a green and a yellow aspect so that if the Elephant and Castle starter is « off », and Blackfriars distant is « on » a yellow light will be exhibited, but if the Elephant and Castle starter and the Blackfriars distant signals are both « off », a green light will be given for the Blackfriars distant. See figure 4.

PART II.

Experimental demonstration.

1) Spectrum of coloured lights used on Southern Railway :

White light.
Red aspect wave length. . 0.638 μ
Yellow aspect wave length. 0.597 μ
Green aspect.

Source of light : electric incandescent focus lamp slightly under run 20 candle power.

White light contains all the visible wave lengths and the green contains too many colours to assign a definite wave length to it.

Red lenses :

Practically only the red light passes through and out of the lens.

Yellow lenses :

Red, orange, yellow and some green passes through the lens. Most of the green, blue, indigo and violet are cut off.

Green lenses :

Red, orange, yellow and blue pass through the lens.

It will be seen that it is difficult to specify the colours comprising the various coloured lenses in use, and the manufacturers have had difficulty especially with the yellow glass. But it is very important from a driver's point of view that the colours of the same aspect shall always be the same tint. The practical way of attaining this therefore appears to establish a standard and to use lenses, or glasses, only that compare almost exactly with the standard.

2) Comparison of light and dark limits of :

Red roundels.
Yellow roundels.
Green roundels.

3) Reflection of light from flat coloured glasses, red, yellow, green.

Reflection of light from coloured roundels, red, yellow and green.

It will be noticed that the roundel is somewhat like a lens and that the image of the source of light is smaller than with flat glass.

4) Light from coloured lens behind a clear front lens.

Light from clear front lens with coloured sheet glass behind.

5) Colour of light given from signal aspects, red, yellow, green when incandescent lamp :

Under run, 33 %.
Slightly over run.
Normal candle power, 24 watts.
Slightly over run.

It will be seen that the colour emitted depends upon the colour of the lens or coloured sheet glass and the state of incandescence of the filament or flame, in other words the temperature of the filament or flame.

If the shade of green glass is light, an intensely brilliant flame or filament in the focus will make the beam of light given out look very much like white light.

It will be noticed the glass or coloured lens to give the signal aspect green is not actually green, but has a decided blue tint with it, but this taken with the yellowish flame of the source of light generally used, we get signal green sometimes called Admiralty green.

6) Comparison of the quantity of light passing through a white red, yellow and green lens from the same incandescent electric light. Coloured lenses transmit light diminishing in this order : White, yellow, blue, red.

The consequence of this is that a white light can be seen from a longer distance than yellow, green, blue or red, and the driver gets a view of the yellow before he would of the red, were red the aspect exhibited at the time.

A further consequence of this is that the source of light (the filament of an incandescent lamp) appears smaller when a red aspect is being exhibited than when a yellow aspect is showing.

7) Compare a beam of light from an ordinary clear lens using an electric incandescent lamp as the source of light and which is ordinarily known as a white light, with the light from a yellow aspect signal lens. It will be seen the colours of both are very much alike.

8) Using a beam of light from a clear lens as in 7.

The effect of placing a sheet of a very light shade of violet glass, between the source of light (the electric incandescent lamp) and the clear lens. It will be seen that the colour of the yellowish beam turns to a white light, sometimes called a lunar white. Colours can be matched in this light. Lenses are sometimes coloured violet to give this shade, but when there is no light behind the lens, the outside surface of the lens appears of a dark violet colour, whereas with this combination (*i. e.*, clear lens of light shade of violet) when the source of light is absent the front glass appears white in the ordinary way.

9) Illuminated signs.

It will be obvious that there should be no chance of an illuminated sign, or other indication, being mistaken for a yellow aspect and the experiment in 8 gives us a means of avoiding any misunderstanding from this cause.

This principle is being used for route indicators and similar purposes.

The route indicator consists of a clear lens with the combination lunar light already described, with moveable discs and the figures or the letters stencilled out of the disc, so that the combination light passes through the stencilled places only and the letters or figures appear brilliantly on the surface of the lens as shown in the experiment. This figure can be distinctly seen and read by the drivers at from 150 to 200 yards away in bright sunlight with an electric incandescent lamp of 20 to 24 candle power in the focus, but at night time when it is dark the letter, or figure, would appear extraordinarily brilliant and from peculiar characteristic of the lens and the source of light, which I will discuss here, the letters, or figures, may run into one another, so that the definition is bad. It may at a distance even look like an ordinary brilliant light, without any shaped figure being seen.

This is due to the fact that : (1) the lens is designed for a point of light in the focus; (2) the source of light, an electric incandescent lamp is by no means a point, consequently the rays of light forming the beam from the lens of an aspect light signal are not parallel as (1) the rays from the focal point will be parallel as they pass out of the face of the lens (2) the rays from the source of light on the left of the focus will pass out in a direction to the right of the main beam, similarly, the rays from the source on the right of the focus will pass out in the direction left of the main beam, with the consequence that there will be a fringe of light of less intensity around the main beam, and the beam will not be shaped very decidedly. Of course the shape of the lens, or the quality of any particular lens, may not be up to the exact standard.

In a similar way, when a number or letter is exhibited on the face of the lens of a route indicator, there will be a tendency for a fringe to form all around the letter, or figure, and produce a blurring effect. It will be obvious that as some of the rays of light from the lens are not parallel, but incline to cross each other, the further away the indicator is viewed, the greater will be the blurring effect, so that a good and definite view could not be had for a distance greater than say 70 yards.

It is so that in sunlight the fringes of the beam, which tend to blur the shape of the letter or figure are not seen, certainly not prominently, as they are in fact neutralized by the brighter sunshine and the brilliantly illuminated letter or figure shows up distinctly.

At night-time when it is dark the fringes are relatively much brighter than the night light and interfere with the definition of the figure or letter correspondingly. To overcome these fringes the voltage on the electric incandescent

lamps is reduced from 12 to 8 volts resulting in the candle power of the lamps being lowered, but being night-time the brilliancy of the letters or figures remain quite bright enough to be seen during the dark hours with equal ease as in the daytime.

In addition, to avoid these fringes, it has been found necessary to provide a very slightly etched glass screen and a fine wire gauge immediately behind the lens. The result of this is to distribute the light from the electric incandescent lamp more evenly over the back of the lens and the rays to pass out more nearly parallel than without the screen and the definition of the letters or figures are much improved.

10) The stencilled discs are arranged to be as close to the back of the lens as possible. Where there are a number of discs it is arranged that normally they rest out of the plane immediately behind the back of the lens, but are brought up to that plane when the particular number is required to be exhibited. If this cannot be arranged and some of the discs have to be further away from the back of the lens than the others, the stencilled letters in the disc are smaller, the further the disc is away from the back of the lens.

The letters on the edges of the lens are apt to be distorted owing to a fault, or the nature of the lens, for instance in the case of 18 the 1 may be distorted into a left hand bow shaped figure. I have overcome this by shaping the stencilled 1 as a right hand bow, *i. e.*, in the opposite direction to the faulty lens, with the consequence that the 1 appears in its normal shape on the front of the lens.

11) If a reflector is used in a light signal aspect, or a route indicator, there will be two beams of light given out from the lens, and the two beams will not necessarily come out of the lens in the same direction. One beam will come from the source of light in the focus of the lens and the second beam being the light from the reflector which will of course not be in the focus.

12) If a coloured light signal aspect is exhibited that is not up to the standard of brilliancy it may be overcome by a powerful white light, which shining direct on the red lens will make the red lens appear white. Similarly with other coloured lenses. This phenomenon is often seen with ordinary signal lights when the sun shines directly on them, especially at sunrise or sunset.

13) Three-beam lamp.

In an ordinary light signal aspect lamp a source of light is placed at the principal focus of the lens and a single beam of light passes out of the lens in a straight parallel beam. The distance between the principal focus and the principal point of the lens, is the focal length of the lens. Now if a second source of light is placed on the right hand side of the first source of light, at say an angle of 45°, so arranged as to be the focal length from the principal point of the lens, and that the angle between the lines from the first source and the second source of light and the principal point shall be say 45°, then a second and distinct beam of light will pass from the second source of light through the principal point of the lens and emerging from the front of the lens as a parallel beam on the right hand side of the main beam and in a direction making an angle of 45° with it. Similarly if a third source of light is placed on the right hand side of the first source, a beam of light will pass from the third source through the principal point of the lens at an angle of 45° from the main beam but on the left hand side of it. Thus there are three beams of brilliant light given out from the same lens all at the same time.

This lamp has been tried in tunnels full of black smoke, in fact, in all con-

ditions found in long tunnels and the light given out by the three beam lamp has been distincly seen by the driver, where an ordinary white, or green, or yellow, or red signal aspect is exhibited, at least from 30 to 40 yards away. In the case of a red three-beam light aspect the black smoke around the signal is illuminated brightly so that in addition to the red light aspect the smoky atmosphere is distinctly coloured, which assists the drivers to locate the signal. Similarly with yellow and green aspects.

The sizes of the side beams are not so large as the main beam, as in the cases of the side beams only a part of the lens is brought into use.

14) The principle involved in this lamp is applied to provide the side light for the light signal aspect as mentioned before. It can be arranged by placing the second lamp on any particular point on the spherical focus that the beam of the side light will emerge from the lens in any direction required, to give the driver a good view of it, either to the right, or left, or above, on a level, or lower than the main beam. This side light is being used in all the colour light four aspect signals at Holborn, Charing Cross and Cannon Street on the Southern Railway.

15) If a white light be placed in the principal focus of the lens and a red light be placed on the right of the main beam and at a point on the spherical focus of the lens so that the lines connecting them to the principal point of the lens are at an angle of 45°, similarly a green light placed on the left hand side of the main beam, then three distinct beams of light will emerge from the lens : 1) the main beam white, 2) the beam to the right of the main beam green, and 3) a red beam to the left of the main beam, all distinct from one another, so that any combination of distinct coloured beams can be arranged. The beams in each case being brilliant and easily seen and separately distinguished — of course the intensity of the beams will depend upon the candle power of the sources of light.

16) The smaller the source of light, provided the candle power is concentrated in say a point, so that it can be got in the focus of the lens the more efficient will be the light and a greater candle power beam be emitted from the lens compared for instance with the light given out from the lens when an ordinary non-focus electric lamp is used. The latter when used gives a very poor result even if a higher candle power lamp is used, compared with a « focus » lamp.

[656 .251]

Scientific study of light signals,

By D. J. McCARTHY,

CHIEF ENGINEER, CHICAGO RAILWAY SIGNAL & SUPPLY COMPANY, CHICAGO.

Figs. 1 to 4, pp. 55 to 62.

(*Railway Signaling.*)

Physics and physiology are closely related in the art of signaling, for the function of all signals is the conveying of intelligence through physical means. Visual

Fig. 1. — Color-light signals should be designed to convey their indications without confusion.

signals convey intelligence through their physical elements by the physiological effect produced upon the human eye. In the design of a railway light signal, the two requirements of physics and physiology must be satisfied simultaneously. The designing engineer cannot neglect one at the expense of the other, if he wishes to produce a signal that will convey proper intelligence in a satisfactory manner. As it is through the eye that such intelligence must be conveyed to the brain, by the medium of light, it is essential that consideration be given to the physiological effect of light upon this organ.

From this consideration, it would seem that the logical procedure would be to work outward from the eye, constructing our apparatus in conformity with its characteristics so as to produce to the best advantage, the physiological effect desired. If this course is not followed and we ignore the physiological and consider only the physical, we may be lead to the construction of a device which, although perfect photometrically and optically, may fail when required to produce the desired physiological effect. Observation tests of such apparatus will show two observers reporting differently as to the effect produced. Even one observer will arrive at different and sometimes contradictory results, when observations are made at various times.

It is well, first, to examine the eye from the point of view of a physicist and then that of a physiologist. In so doing, we find the eye to be an optical instrument, possessing accuracy of construction and refinement of adjustments, far exceeding that which has been obtained in any optical device so far devised. We also find that it possesses some imperfections which could not be tolerated in precise optical instruments. Due to these imperfections, some physicists deem the eye an imperfect device when compared to some lens combinations that have been devised. But from

a physiological view point, these imperfections of the eye become advantageous and make it the most perfect organ, we can conceive of for the purposes for which it is used.

A study of the eye.

The optical equipment of the eye consists essentially of a compound lens, nondistorting and rectilinear, working at F4 in conjunction with an automatic adjusting iris diaphragm. It can be considered as a camera, producing physiologically full size motion pictures in natural color. It is also a range finder and, to some extent, a photometer. The two most striking characteristics of the eye which have not yet been produced in a man-made optical device, are the automatic focal adjustment of the lens and the automatic diaphragm-changing aperture regulating the amount of light entering the eye. The latter affects, to a great extent, the visibility of the light signal between day and night. This will be discussed later.

In the ordinary camera and other optical devices of like nature, the focal point of the lenses is fixed for objects a given distance from them. To focus objects at any other distance, it is necessary to change the position of the lens. The position of the lens in the eye is fixed, but when it is directed at an object, the shape of the lens is changed so as to bring the light rays from that object to a focus at the retina. This characteristic is termed « accommodation » by the physiologist.

From a physiological standpoint, the main factors for consideration in designing a light signal are : 1) The effect of the spectrum colors upon the retina, with respect to combinations of colors and with respect to the sensitiveness of the eye to colors of various intensities; 2) the persistence of vision for various colors at various intensities; 3) the minimum and maximum visual angles; and 4) the minimum and maximum intensities of illumination for good vision.

From a consideration of the effect of different colors upon the retina the proper colored lenses or roundels to be employed can be determined. A consideration of the maximum and minimum visual angles will determine the proper diameter of the lenses. From a consideration of the maximum and minimum illuminating intensities the amount of energy required to produce the necessary light flux can be determined.

Color of lenses.

In railway signaling, four colors — red, green, yellow and white — are in general use. Signal departments of various railroads having adopted as standard, some combination of the colors.

Red has always been employed to signify danger. The natural physiological effect of red upon the mind is to produce a sense of danger. It is also a natural physiological effect to associate white with clear or safety.

For indicating a condition between absolute danger and absolute safety, green has long been used and for a three indication signal, red, green and white were adopted. For certain physical as well as physiological reasons, white has proven to possess undesirable characteristics as a safety indication. In later practice, green has been substituted as signifying safety and yellow, caution. This combination of red, yellow and green is more commonly used at the present time than red, green and white.

The various colors affect the eyes in varying degrees of sensitivity. Sensitivity to different colored lights seems to depend upon the wave length and frequency, beginning with red, gradually increasing to a maximum between yellow and green, and decreasing toward the blue and violet. From this it is evident

that yellow and green are the colors most sensitive to the eyes, the degree of sensitivity depending on the intensity of the color. For low intensity, the eye is more sensitive to the action of the green rays than to those of yellow or red. For high intensities, the yellow predominates. Sensitivity, as referred to here, pertains to visibility and not to that sensation caused by lights of high intrinsic brilliancy, which causes dazzling and discomfort to the eye. The sensation causing discomfort is known as glare and is often popularly confused with sensitivity. The causes producing the sensation due to glare must be guarded against in the light sources used for railway light signals.

What causes glare?

A predomination of glare may magnify the faults due to a tendency of color blindness in eyes that have to be constantly trained upon such lights as is necessary in high speed train operations. It is difficult to give a clear definition of glare, therefore we will consider only the most prominent cause, which is the entering into the eye of radiations, other than those which produce light to which the eye is sensitive.

For pure green and yellow light, for which the eye has the highest sensitivity, all the radiations produce visibility. The radiation or waves which produce sensation of light are of the same nature as heat. Therefore the radiations entering the eye which do not produce visibility produce heat. The absorption of heat for a given light sensation, is much greater for red and violet light than for yellow and green lights. The effects of overheating is manifested immediately from lights of long wave lengths, but the eye recovers quickly. The effect of the short wave lengths is not felt for some time, but recovery is very slow.

Less harm is done by red radiation than violet; this is due to the long wave length of the red and the short wave of the violet; therefore lights containing violet and ultra-violet rays are objectionable, for signal use. White light contains a larger percentage of violet and ultra-violet rays than any other light, and where such lights have been in use, it has been found necessary to make provisions for subduing them. Two methods have been employed, one by placing a wire screen in the path of a light beam, the other and more effective means is to filter out the violet rays. Ordinary window glass acts as a filter for part of the violet rays. A glass giving complete protection was invented some time ago by Drs. Schang and Stockhausen. To this glass, they gave the name of Euphor. This glass filters out completely the ultra-violet rays and does not absorb more than 2 to 3 % visible light rays.

The colors, as derived prismatically from sunlight, have a high percentage of visibility whereas in those derived from artificial lights, the percentage of visible radiation is small compared to the power radiation which enters the eye. In the prismatically derived colors, the only radiation or wave lengths entering the eye, are those that produce the color sensations, excepting at each end of the spectrum, that is, in the ultra-red and violet rays. In the light signal, the colors are not derived prismatically but by a process of filtering or absorbing light rays from a radiant source. The colored roundels or lenses placed before a lamp do not produce color, these glasses act simply as filters preventing all colors except the one desired from passing through. Thus a red roundel does not produce red light, but by preventing the passage of all other colored rays, the red rays from the light source are made visible to the eye. If the source contains no red rays, the result will be black denoting the absence of color.

It is essential therefore, that the light source be capable of producing the necessary colors. The most efficient lens combinations or the highest quality of colored glass cannot compensate for a deficiency of color in the light source. Here, the light signal designer must appeal to the lamp manufacturers who are, we find, concerned in producing a lamp that will give a pure white light similar to sunlight. This result, the manufacturers have accomplished to a very high degree, but not by means of a lamp that has the same spectrum as sunlight, but by one that produces a white light sensation to the eye by the combination of two or more complementary colors. Here too the lamp designer must, like the signal designer, give consideration to the physiological. This, he does by combining red, yellow and green light in the proper proportions to fool the eye into believing it is seeing white light. Unfortunately when producing this effect, there is also produced a large number of heat and invisible rays that produce glare and other discomforts to the eye. This is especially true when the light enters the eye directly from the lamps as is the case when observing a light signal.

In electric lamps now used for signals, the percentage of red, yellow and green rays is not the same for each color. The percentage of visible radiation of the lamps is small compared to its total power radiation, which is in the form of heat and invisible rays. In the electric lamps, so far developed, the percentage of visible rays of any one color is not sufficient to produce enough candle-power to allow of projection for long range signaling. It is necessary that other rays be allowed to pass through the roundels in the proper proportions to give the necessary penetration and at the same time cause in the eye the physiological effect of the color desired. The red rays, which are low in visibility, can be made to appear much brighter if a small percentage of yellow rays, which are high in visibility, are allowed to enter the eye at the same time. The yellow causes a light sensation in the eye and if their percentage is not too high as compared to red, the eye will convey to the brain a sensation of red much brighter than if only red rays were used.

Reflected light is composed largely of visible rays.

If the light from a lamp falls upon a colored object, the eye will observe the objects by reflected rays; these rays will have only the color value of the objects illuminated. Very few rays other than the visible ones enter the eye by reflected light from colored objects, all other rays being absorbed by the object. It is this effect which we endeavour to produce in the light signal by taking into consideration the spectrum characteristics of the lamp employed and the composition of the colored lenses or roundels used. It is not only necessary that the composition of the colored glass used in the lenses or roundels be such that it will transmit the desired color only, but that it will also prevent the transmission of undesirable heat radiations and light waves which cause glare.

If a lamp could be produced giving only the colored rays required, this problem would be much simplified. Colored lenses could be dispensed with and a considerable amount of the energy, which in the present light source is wasted in producing invisible heat rays, -could be used efficiently.

Another physiological problem for consideration is the possibility of producing false color sensations in the eyes. Signal men, as a rule, consider the term « false indication » to mean the effect produced by a head light beam or other foreign light reflected from the signal. What we refer to here, is the effect pro-

duced when the eye is suddenly directed from one color to another. It is due to the characteristic known as « persistence of vision ». A light sensation in the eye does not cease at the same instant that the light producing it is extinguished, but persists for some appreciable time afterward. For example; when the eye is directed for some time on a red light, which is suddenly replaced by a green one, the sensation is not that of green, but a combination of green and red. This sensation will prevail as long as the sensation of red remains. Owing to this characteristic the colors that succeed each other in giving signal indications from danger to clear, should be selected so that the combination of the danger and caution colors will not momentarily produce the physiological effect of the color indicating safety. Referring to the combination of the spectrum colors, it has been found that 57 % of them can be produced by combination of two or more of the others. Red and green mixed in proper proportions will produce white. In a signal using red for danger and white for clear, the caution indication should be some other color than green. Yellow and red will not produce white, therefore yellow can follow red without the physiological danger of producing the white sensation in the eye.

The safest color to use for giving a clear indication is one that cannot be produced by a combination of any other two colors. Three of the spectrum colors have this property; they are red, violet and green. As violet rays give poor visibility, green is the best choice for giving the safety indication. Yellow ranking next to green in visibility and absence of glare makes it a desirable color for a caution indication.

The persistence of vision in a physical sense would seem at first thought to be an imperfection in the eye, but when we consider that without it the moving picture would not be possible, we see that it becomes an advantage from a physiological viewpoint.

Proper size of lens

To determine the proper size of lens, we should first note which characteristic of the eye enables us to detect the relative size of objects. We find that this is due to the angle at which light rays enter the eye from the extreme edges of the object viewed. This angle is known as the visual angle.

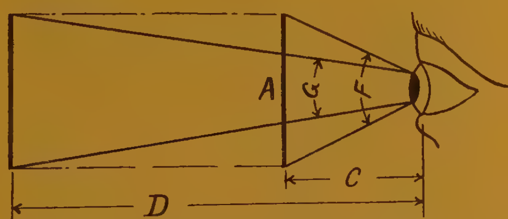


Fig. 2. — Relative size of an object depends on the visual angle.

Figure 2 shows a diagrammatical representation of this angle. The rays from the object A at C distance from the eye will have an angle F. The same object at D distance will have a smaller angle G and will have a relatively smaller apparent diameter than when at A. From this, it will follow that as the object recedes from the eye, its apparent diameter will be decreased until the object disappears. This angle is known as the minimum visual angle which for a normal eye is an angle of 1 minute (1/60 degree). At this angle, the eye can see an object only as a point; in order to see it clearly and with comfort the angle of the object must be at least five times this or 5 minutes. The diameter of a disc, which is comfortably visible is given by the formula :

$$A = \frac{2\,D\pi}{21\,600} \times 5$$

in which A = diameter in inches or feet

and D = distance in inches or feet. At a distance of 4 000 feet, which is about the maximum range required of the light signal, a disc to be clearly seen by reflected light, must have approximately a diameter of 66 inches. From such a disc, the light rays are entering the eye from all parts of its surface and all at different angles to each other. It is not practical to construct, for light signal use, a lens or reflector combination having a diameter of 66 inches, but fortunately the physiological conditions are somewhat different when light enters the eye in a projected beam from lenses or parabolic reflectors. In such cases, to a certain extent, the rays are parallel to each other, and not at different angles as in the case of the disc.

This is illustrated in figure 3 which shows that the light rays emanating from the luminous lens B are parallel to each other, entering the eye in parallel lines instead of angles. The rays do not form a visual angle on entering the eye, therefore the physiological effect of the size is not present and the eye cannot determine the size of such a light source. Because of this, it can be seen that for long distances, the eye cannot determine the relative size of two parallel light sources. Even, if they are placed side by side, a 3-inch diameter lens will appear as large as a 10-inch diameter lens. Of course the field of vision will be in relative proportion to their size; that is, the eye will detect the light from the larger lens easier than from the smaller one. What then, would be the apparent size of a light source which will send only parallel rays into the eye? This can be explained by referring to the visual angle at which objects will come into focus at the least muscular strain in the eye. When the eye is directed at an object and not moved, the maximum angle at which the object is in sharp focus is about 1/2 degree, everything outside of this is indistinct. This is known as the maximum visual angle. We are therefore, able to estimate directly the size of objects by muscular sensation of strain in converging our eyes to bring the light rays from the object to a focus at the retina of the eye. The amount of this convergence depends upon the angle at which the light rays enter the eye. It also depends upon the distance we are from the object, the farther away the less divergence; and it is a physiological fact that for the normal eye, objects over 100 feet away come into focus without any muscular sensation.

Due to this fact, the eye when unaided by intervening objects, can judge fairly accurately the size of objects not exceeding a distance of 50 or 60 feet, but for distances above 100 feet it fails entirely. An interesting example of this is shown in our ordinary estimate of the apparent size of the sun and moon; each appears to be about a foot in diameter. When we look at the moon in mid-heaven, our eyes directly inform us that it is at least a 100 feet away; on the other hand, due to the absence of intervening objects, we instinctively estimate the distance as the least possible, consistent with the non-convergence of our eyes, and accordingly imagine the size of the disc to be about that of a ball which at a distance of 100 feet or so, would subtend the same angle of 1/2 degree, that is, about a foot.

When we look into a parallel beam of light, the lens of the eye assumes its flattest form which exerts the least muscular sensation in order to bring such rays to a focus on the retina. This sensation tells us that the object is over 100 feet away and its apparent diameter will be the same as an object 100 feet distant, which subtends the same angle as the maximum visual angle. This diameter will be approximately 12 inches or 1/2 degree.

Apparent size of any parallel light source.

Therefore a strong parallel beam, although its source may be several thousand feet distant, will cause the physiological effect of size to be one foot in diameter. This is true, even though the light in reality may be very small or very large. This is evident in figure 3, in which it is shown that considerable of the light rays do not enter

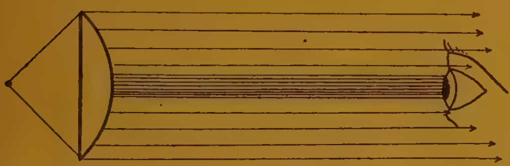


Fig. 3. — Parallel rays do not reveal the size of the light source.

the eye at all, but the amount which does enter is the same for a small or large lens, being the amount falling within the diameter of the pupil of the eye. It follows from this, that a light signal source would not necessarily have to be of large dimensions and that possibly a 3-inch lens would be sufficient to give a long range indication. This would all be true, if the light rays were absolutely parallel which can only be true with an infinitesimally small light source and as all light sources have physical dimensions, it is not possible to send out all the light rays parallel within a narrow beam from a small lens.

It is physically impossible to keep the eye within this beam when approaching a signal at close range. While at a range of 4 000 feet, the eye would see a light source as one foot in diameter, only while it is situated in the beam, but as it approaches the light, and on account of the physical relationship of the signal to the track, the eye is gradually drawn out of the parallel beam and is affected by the diverging and converging rays due to the inaccuracy of the lenses and the physical dimension of the light source. Under these conditions the eye commences to see the light source somewhat under the same condition as the discs referred to above. With the lamps available and the lenses so far developed, it is not physically possible to obtain a maximum angle of light from the lamp with a lens less than 4 inches in diameter. These lenses must be used with a second lens, in order to give a parallel beam. From this, it would appear that the minimum diameter of the lenses, due to physical conditions, could not be less than 5 inches. As to the minimum size for physiological reasons, it follows that when the eye approaches within 500 feet or less, on account of diverging and converging rays and also the loss of the parallel beam, the lenses must be of such a diameter as to subtend an arc for comfortable vision.

Assuming that the conditions referred to take place at 500 feet and using the formula referred to above, we find that the diameter of a disc clearly visible at that distance would be approximately 8 1/2 inches. At this diameter the light source would appear as a point, if all the rays were convergent. By mounting the signal at the proper height and distance from the track, the eye can be kept within the direct ray of the beam within a distance much less than 500 feet, so that the effect of the parallel light will aid in giving the physiological effect of a 12-inch diameter lens within possibly 200 feet of the signal, from which distance, the eye can readily compare the size of the illuminated lens with surrounding objects. It has been found in practice that a 8 3/8-inch lens gives satisfactory illumination for signals that have to be mounted in such a position with reference to the track that the axis of their light beam will vary approximately 4 to 20° from the line of vision between far and close up obser-

vations. A signal having an optical equipment embracing the same light flux as the 8 3/8-inch combination, but using a 5-inch objective lens, will give equal results if it can be so mounted that its light beam axis will be within 4° of the line of vision through the whole range of observation.

The advantage for the longer ranges is in favor of the smaller lens for the reason that the light flux per unit area is greater than for the larger lens, therefore the penetration would be greater. Where the ranges are the same, advantage can be taken of this fact by reducing the light energy for the smaller lens.

Primarily, the visibility of the signal is due to the amount of light entering the observer's eye at any point within the signal's range. We must, therefore, determine the amount of light necessary to affect the eye for comfortable vision and then give consideration to the problem of projecting this amount to the extreme range of the signal. For the average eye to read comfortably ordinary print on white paper, it has been found necessary to illuminate the paper with a candle power of one foot-candle. The visibility of light varies directly as the intensity and inversely as the square of the distance from the source. Therefore, to see clearly, by reflected light, the 66-inch disc referred to previously at a range of 4 000 feet, the illuminating source would have to be of 16 000 000 candle-power. Such an illumination would be as impractical as a 66-inch lens, but the light signal does not give indications by reflected light, but by sending a direct ray into the observer's eye. In giving consideration to glare, we found that this characteristic has some physiological disadvantages, but when considering visibility and range, we found it had some physical advantages in reducing the amount of light energy required to give a signal indication. The amount of light entering the eye is dependent on several factors, the most important of which are the intensity of

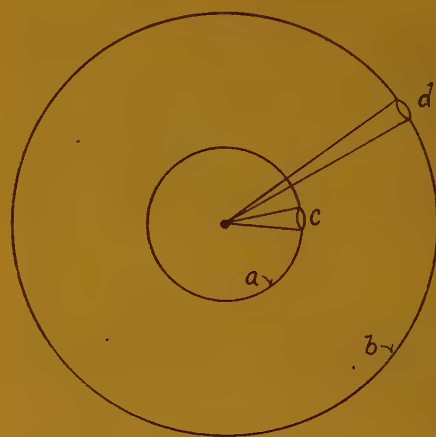


Fig. 4. — Spherical distribution of light flux.

the light source, the distance of the eye from the source and the area of the lens of the eye exposed to the light. In order to see more clearly the effects of these conditions it is necessary to review some fundamental considerations with respect to the distribution of light.

Inverse square law not applicable to parallel rays.

From most primary light sources, the light flux is radiated in all directions. Keeping this fact in mind and referring to figure 4 let us assume an infinitesimal light source at the center of the circle A and B. The light source is of one candle-power. The radius of circle A is one foot and that of circle B, three feet. An observing eye placed at C, will be illuminated with one foot-candle but the one at D, in accordance with the inverse square law will receive an illumination of only 1/9 foot-candle.

Assume that A is the diameter of a sphere. As the light is radiated in all directions, it will uniformly illuminate the inner surface of such a sphere. If all the light on the spherical surface A

were directed into the eye C, the increase of intensity would be in proportion to the ratio of the area of the sphere to that of the eye. The iris diaphragm of the eye is capable of closing and opening the pupil between 1.5 and 4 mm., from which we can assume for our illustration that C and D have a diameter of 1/16 inch the area of which is 0.00307 square inch. The area of the sphere A is 1 809.6 square inches. Therefore the candle-power illumination of C will be :

$$\frac{1\,809.6}{0.00307} \times 1 = 589\,446.$$

The area of the sphere B is 16 286 square inches, therefore the candle-power illumination of D will be :

$$\frac{16\,286}{0.00307} \times 0.11 = 583\,540.$$

In comparing these results, we find that the inverse square law does not hold true, for if it did, the results for D would be 65 444 candle-power. This illustration serves to show that when light is projected in a parallel beam from lenses or reflectors, it does not wholly comply with the inverse square law. This fact enables us, by the proper use of lenses or reflectors, to project a powerful beam of light having many thousand candle-power from a small light source.

To cause a light sensation, the light source can be of lower candle-power where the light ray is sent directly into the eye, than where the ray is reflected. The minimum luminosity of lights just visible is 0.00032 foot-candle for white, 0.0011, for green and yellow, and 0.032, for red. From these figures, we can assume that 0.032 candle-power must be projected to the maximum range of the signal in order that the eye can observe it.

The intensity of a projected light beam depends upon the angle of light embraced by the lens or reflector and by its diameter. Of all projecting means so far devised, the parabolic reflector can embrace the largest angle of light. But as reflectors have the physical possibility of causing phantom indications by foreign light entering the reflector, we will give here, consideration to lenses only as they do not possess this characteristic.

With well designed lenses, it is possible to embrace 170° of the total light flux. If this flux is projected into a beam 6 inches in diameter, the intensity of such a beam will be 2 000 times the candle-power of the source. From which it follows that with a 5-candle-power lamp, it is possible to project a beam of 10 000 candle-power.

The difference in intensity of a light beam to the eye — between night and day — is due to the physiological fact that the iris diaphragm of the eye is subjected to a marked expansion and contraction due to the action of light upon it. In bright sunlight, the diaphragm is contracted to a diameter of 1.5 mm., and in darkness, it is expanded to 4 mm. The amount of light that can enter the eye is governed by the area of the diaphragm openings, which opening, the physiologist terms the pupil of the eye. It follows that in observation of the light signal at night, the eye will receive over 7 times the illumination than at midday. Daylight observation of the signal can be favored by shading as much as possible the engineman's eye from direct day light. In practice, the ordinary engine cab favors this condition. The main disadvantage due to the increased illumination at night is that of glare. But in a well designed signal in which consideration has been given to producing the proper color filters, this objection can be practically eliminated.

[385 .589 (.42)]

The railway strike in Great Britain. (1)

How London & North Eastern Railway met situation created by the general strike,

By Sir RALPH L. WEDGWOOD,

CHIEF GENERAL MANAGER, LONDON & NORTH EASTERN RAILWAY

(*Railway Age.*)

The British public know what a national railway strike means. There was one in August, 1911, because the railway companies, with the exception of the North Eastern, would not recognize trade unions and the men were dissatisfied with the conciliation boards which had been set up four years earlier. A second took place in 1919 about the fixing of wages on a new basis to suit the conditions caused by the war.

For the first time last month the people felt the effect of a simultaneous stoppage of the railways, the docks, the underground or « tube » lines, the omnibus services, the printing trades and a number of other productive industries. The coal miners had automatically ceased work on 1 May on the breakdown of the negotiations which the government had been conducting between them and the coal owners. Thereupon, the Trades Union Congress declared a « general strike » to take effect at midnight on Monday 3 May. The orders of the Congress were faithfully obeyed by the unions concerned, and nearly 3 500 000 stopped work.

The country was undismayed. It managed to transact much of its ordinary business in spite of the strike. The government organization for meeting the emergency worked well. There was an abundance of food. The power stations were kept going. Most newspapers were issued in an abbreviated form. In a few days it was evident that the services of the strikers were not indispensable and many of them began to return to their posts. Soon after mid-day on 12 May the Trades Union Congress informed the government that it had decided to terminate the general strike unconditionally. The railwaymen were left to make terms for their reinstatement with the companies as best they could, and a settlement was reached on Friday 14 May. Thus ended the most formidable strike which has ever taken place in Great Britain, and it is thought that some account of the experience of one of the main railways during this exciting fortnight will be of interest to American readers.

The strike on the North Eastern.

The London & North Eastern is the largest carrier of mineral traffic in Great Britain. It has a monopoly in the coalfields of Northumberland, Durham, the Lothians and Fife. It has also huge interests in the coalfields of Nottinghamshire and Yorkshire as well as a share in the traffic from the pits in Lanarkshire, Lancashire and North Wales. In 1925 the company carried 87 000 000

(1) Sir Ralph Wedgwood, the author of this article, was chairman of the Controlling Committee of the Railway Information Bureau during the British general strike.

tons of coal and coke. Twenty-five million five hundred thousand tons of that quantity were shipped at docks and staiths owned by the railway. The effect of a coal stoppage alone on the company's prosperity is bound to be serious. The wider cessation of work hit the Company very hard. Owing to the location of many of its lines in industrial areas, the great majority of the staff are staunch trade unionists, and only 12 % of the personnel stuck to their posts when the strike was called. Seventy-six engine drivers out of 11 500 remained at work. Eighteen firemen were all that could be mustered out of a similar number. One hundred and forty-three guards were available, representing 2 % of the full strength. Signalmen were more loyal : 503 of that grade « stayed in », or 5 1/2 % of the number in the grade. On the other hand only 57 shunters out of 5 300 reported for duty, so that the Company was desperately short of the men whose services are essential for the movement of traffic.

It should be remembered that the 167 000 men who went on strike had no quarrel with the Company. They had high wages in comparison with many trades, an eight-hour day, a guaranteed week, conciliation machinery for remedying grievances and the protection of the Railways Act of 1921.

When the National Union of Railwaymen notified its intention to call a strike the London & North Eastern replied pointing out the liability for damages incurred by the men in breaking their contracts of service and reminding them that if lives were endangered by their action, they would render themselves liable to criminal prosecution.

A warning notice was also posted in the following terms over the signature of the chief general manager :

The Company have received an intimation that a number of their staff have been instructed by their Trade Union to cease work today, Monday, 3 May.

The Company desires to impress upon the staff that if they leave work in the manner indicated they will be breaking their contract of service.

The Staff are reminded that they cannot legally terminate such contract except by giving proper notice in accordance with the terms of their engagement.

At the same time the Company issued a warning to the public in these terms :

The public are informed that the Company have received an intimation that a number of their servants will leave their employment without proper notice on Monday, 3 May. The Company, therefore, intimate that they cannot at present undertake responsibility for the carriage of passenger and merchandise traffic, and will not be liable for any loss which may arise.

The object of these notices was to let both the men and the public know at the earliest possible moment exactly how they stood and, throughout, the Company consistently held to this policy of taking everyone into its confidence.

Special organization formed.

At 3 p. m. on Monday 3 May, the Company brought into force a special organization which it had prepared for dealing with emergencies. The ordinary departmental arrangements were suspended for the time being and the strike business was conducted through three controls reporting to the chief general manager at King's Cross. One control at Liverpool Street, London, administered the affairs of the southern area of the system. The second at York looked after the north eastern area and the third at Edinburgh took charge of Scotland. Each control was supervised by the divisional general manager for the particular area and consisted of such of his departmental officers as he assigned for the purpose. The area control worked

through district controls at the principal centers. The southern area, for example, had district controls at King's Cross, Stratford, Marylebone (all in London), Cambridge, Norwich, Nottingham, Doncaster, Leeds, Manchester and Grimsby.

This special organization had the advantage of pooling the resources of all departments. It provided machinery for collecting and transmitting information to headquarters. Conversely, orders were speedily distributed through the controls to all points on the line. The best use was made of telephone and telegraph — a matter of importance, as many of the operators had left duty. Finally the controls dealt promptly with emergency problems as they arose by direct conference of the officers concerned. The arrangements worked well and relieved the chief general manager of executive worries so that he could give all his time to questions of policy.

The strike began at midnight on 3 May. At first the unions offered to allow men to work certain traffics, but the London & North Eastern Railway Company declined to admit the right of the men to select their work. All men who declined to perform any part of their normal duty were dealt with as on strike. On 5 May the National Union of Railwaymen simplified matters by instructing its members « to handle no traffic of any kind — foodstuffs or otherwise ».

Progress of the strike.

The first day of the strike, Tuesday 4 May, was difficult, and only 84 trains could be run. At the request of the government priority was given to milk trains bringing supplies to London and the larger provincial towns. The bulk of the engine power available was then concentrated on passenger rather than on goods train services and preference was also given to suburban over main line services. The steady growth of the services is shown by the following table:

	Number of trains run	
	passenger.	goods.
4 May . . .	84	...
5 — . . .	281	6
6 — . . .	559	11
7 — . . .	682	20
8 — . . .	757	23
9 — . . .	No Sunday services	4
10 — . . .	945	73
11 — . . .	1049	105
12 — . . .	1105	171
13 — . . .	1161	174
14 — . . .	1191	218
15 — . . .	1403	237

The work of the first two days was satisfactory in the face of the difficulties to be surmounted, and the chief general manager issued a message of encouragement to the loyal staff, which is reproduced below.

I should like all the staff to know how well things are going, and how much the government and other authorities are impressed with the great effort which the railway companies are making.

Yesterday we ran 148 trains : today we have passed the 200 mark. There is every prospect of a steady and rapid increase in the train services from day to day. London railway recruiting offices are overflowing with volunteers, many of whom are of the best kind for our purposes. From all we can learn the experience at other centers is the same.

Fifteen milk trains ran this morning, and special attention is being given now to fish and other perishables. A dining car will be run on the York train tomorrow. These things are small in themselves but every improvement in our services that can be effected shows that we know how to keep the flag flying, and wins us further support from the public.

I take this opportunity to thank all the staff who have remained loyal to their service for the magnificent work which they are doing. I know that many of them are working under conditions of great difficulty, often

involving long and irregular hours of duty. If we carry on as we have begun, we may look for a speedy end to the present situation.

The passenger trains on 6 May included the « Flying Scotsman » from London crowded with passengers, and on this day the London & North Eastern Railway ran the first restaurant car during the strike by the 9.00 a. m. from London to York. The passenger receipts at King's Cross (London) on 8 May, were only 40 % below receipts for the corresponding day in 1925. On the same day the boat train service from London to Harwich was resumed and the two boats for the Hook of Holland and Esbjerg got away promptly. So well were things going that on Sunday 9 May, the Chief General Manager indited another message to the staff which is again quoted in full.

After five days of strike we can now take stock of the situation.

On Saturday we ran 757 passenger trains, equal to 12 % of our full normal service. There has been a steady improvement day by day, and we can confidently anticipate a further advance. The Flying Scotsman is again running and has been crowded. The continental boat train for the Hook of Holland also started again on Saturday night, and sailings from Parkeston Quay are resumed.

The freight service has made a good beginning; fish, butter, meat, vegetables, petrol and live stock are now being moved.

The position is far better than could have been anticipated, and is the result of the united and untiring efforts of the staff, who have remained loyal to their service.

Our aim must now be to develop still further the services already in existence, and particularly the freight service carrying essential commodities.

Volunteers of an excellent type are being trained in large numbers, as drivers, firemen, signalmen and guards.

The Company wish it to be known that the staff who remain loyal to them may look in the future to receive the fullest support and protection which the Company can afford to them.

Staff now on strike who return to duty in the immediate future will be welcomed and will receive the same measure of protection, provided they are willing to join with us wholeheartedly in any suitable capacity and help to get the wheels turning.

Throughout the strike sailings of the Company's steamers from Hull and Grimsby to the continent were continued in spite of the embargo placed on bunkering in this country, and on 10 May the steamer services run by the Company on the river Clyde were resumed. On 14 May, the day of the strike settlement the passenger train mileage was over 27 000 miles, or 15 1/2 % of the normal figure. The goods train mileage was 8 017, representing 5 1/2 % of normal. The effort to close the railway had failed conspicuously.

How the strike collapsed.

The collapse of the strike was hastened by the return to duty of some of the strikers. By the end of the first week over 700 men had come back. This number was doubled on 10 May. Two days later the chief general manager published a grave warning to the strikers in these terms :

The London & North Easthern Railway Company wish to notify their staff now on strike that at the conclusion of the strike the number of staff whom the company can employ will be materially reduced.

The effect of the strike upon the trade of the country must be to diminish substantially the tonnage of traffic to be handled, and it will necessarily take a considerable time for trade to recover.

The Company wish it to be understood that at the conclusion of the strike they will give preference for employment to those of their staff who have remained at work or who offer themselves for re-employment without delay.

This notice had an immediate effect.

On 13 May the number of strikers back at work jumped to 5 570 and a further lot of 770 came in on the next day. Each of these men was handed a notice saying :

> You are hereby re-engaged, but your engagement is on the understanding that the Company reserve any rights they may possess in consequence of your having broken your contract of service.

Many of the men were very suspicious about this notice and believed that it foreshadowed a reduction in wages. This led the Company to issue the following announcement to their men on 13 May.

> Rumors have been circulated to the effect that the Railway Company propose to take this opportunity of reducing the wages of their drivers, firemen or other grades; also that the Railway Company propose, in taking men back into the service, to take them on as new entrants, as a result of which the men would receive lower rates of pay as well as losing the benefits of their seniority.
>
> Both these rumors are entirely without foundation. Men accepted for re-employment will come back at the rates of pay which they were receiving before the strike, and without loss of service.

Many volunteers employed.

A second great factor in breaking down the strike was the employment of volunteers in place of the regular railwaymen. The managing and clerical staff of the Company came to its help in a way which was beyond all praise. Outside assistance was also enlisted freely. On 4 May, the Company advertised that engine drivers, firemen, cleaners, motormen, guards, signalmen, shunters, carters, vanmen, stablemen, porters, general laborers and despatch riders were needed for urgent and essential services in connection with the working of trains. The posters were followed up by an appeal broadcast by wireless. Before the strike came to an end tens of thousands of volunteers were enrolled and over 10 500 were employed. No skilled men were turned away. At King's Cross (London) Station alone, nearly 7 000 volunteers were enrolled and of this number 1 688 were posted to the grades which are most intimately connected with the handling of traffic.

These volunteers were from many sources. Men were released from the Royal Air Force and others came from universities, medical schools, banks and offices. The country's unemployed hastened to seize an unprecedented opportunity of temporary employment. Women came forward in large numbers and many served in the canteens. The whole of the Pullman Car Company's staff on the London & North Eastern Railway volunteered for service in a body and were usefully employed in catering for loyal employees and volunteers. Naval ratings kept the company's electric power stations going. A few volunteers were employed at once as drivers, firemen, guards and signalmen. Others had to be trained and were passed through schools for footplatemen, guards and signalmen, which were established under the direction of qualified instructors at various centers. Men from these schools were sent to work with regular hands or experienced volunteers before taking charge of work on their own responsibility.

The volunteer offices were in constant touch with the controls and sent out batches of men as required. Seventy-five stablemen and provendermen, for example, were asked for at 6.00 p. m. one night : the men were provided and on duty at 6.00 a. m. the following morning. The locomotive and traffic departments had the first call upon volunteers, but men were also taken in the engineering, telegraph, hotels and other departments.

All volunteers willing to accept remuneration for their services were paid the current rate of the grade in which they

were employed, and overtime, night duty and Sunday duty was paid for at the standard rates.

It was realized that careful rostering, feeding and resting arrangements were essential if the staff were to carry through to the end successfully. Hours, inevitably, were long, but as far as possible staff were put on regular shifts of 8 to 12 hours and every effort was made to provide comfortable sleeping accommodation.

A thoroughgoing distribution of food was rapidly organized in which hotels, dining cars, and canteens played a most valuable part. Entertainments were arranged at various centers for the benefit of loyal workers and volunteers. Apart from those members of the staff who were required to be available at all times, employees were encouraged to travel daily to and from their homes. Motor cars were available for those who could not make their own transport arrangements.

Publicity an important factor.

A third reason for the success of the Company has been hinted at already. This was the care given to publicity. In no previous strike in Great Britain has the Company's case been put so fully and promptly before the country. As a result public opinion was unreservedly with the railway throughout the struggle. Much credit for this is due to the Company's advertising manager, who organized the issue and distribution of all public announcements and «time sheets». These were posted with the utmost dispatch. The time sheets kept pace very well with the developing services. Some difficulty was experienced at first in getting material printed, but until the printers resumed some of the company's own staff turned themselves into compositors and produced excellent work. The advertising manager also arranged with the British Broadcasting Company for the broadcasting of wireless messages about train services and the general railway position. Another effort of his was the publication of the *London & North Eastern Railway News*. The first number appeared on 8 May, and 6 were issued in all. In the absence of daily newspapers the *London & North Eastern Railway News* kept the staff informed of the progress of affairs besides acting as a useful medium for outside publicity.

The touch maintained with the public was particularly valuable when the general strike ended. There was a measure of disappointment that the railway stoppage did not end at the same time. On 13 May, while notifying the public that the regular service of trains would be resumed as quickly as practicable and that the emergency services would be amended and increased, the Company announced that it had been unable to arrange with large numbers of its staff to resume duty immediately. The staff still on strike were informed that they would be reengaged as and when work was available for them subject to two conditions :

1. Every railwayman who left his work without proper notice has committed a breach of contract and has thereby involved the Railway Company in heavy losses. The Railway Company are notifying all the men who offer themselves for re-employment that the Company reserve any rights they possess to damages for breach of contract.

2. A number of the Company's staff occupying positions of responsibility in which they were entrusted with the supervision of other members of the staff have gone on strike. The Company propose to examine these cases individually and to decide in each case whether they can re-employ the man concerned in the position which he occupied before the strike. Pending this consideration they are not prepared to re-employ the men concerned who in addition to their breach of contract have been guilty of a breach of trust towards the Railway Company.

The Company expressed the opinion that its action on these two points was essential if the future was to be free from the unwarranted disturbances which had too often occurred in the past and asked for public support in insisting upon these safeguards for future peace and discipline. These announcements were repeated in circular form to the volunteers with an urgent request that all volunteers should continue to place their services at the disposal of the Company until the matter had been brought to a satisfactory conclusion. The volunteers, almost to a man, honored this request.

Terms of settlement.

When it was found that the railways were not prepared to take back all their men immediately and unconditionally, the unions called upon their members to continue the strike. There was little heart left in the fight and after several meetings between the unions and the railway managers a settlement was reached on Friday 14 May.

The terms of the settlement were these :

1. Those employees of the Railway Companies who have gone out on strike to be taken back to work as soon as traffic offers and work can be found for them. The principle to be followed in reinstating to be seniority in each grade at each station, depot or office.

2. The Trade Unions admit that in calling a strike they committed a wrongful act against the Companies, and agree that the Companies do not by reinstatement, surrender their legal rights to claim damages arising out of the strike from strikers and others responsible.

3. The Unions undertake :

a) Not again to instruct their members to strike without previous negotiations with the Companies;

b) To give no support of any kind to their members who take any unauthorized action;

c) Not to encourage supervisory employees in the Special Class to take part in any strike.

4. The Companies intimated that arising out of the strike it may be necessary to remove certain persons to other positions, but no such person's salary or wages will be reduced. Each Company will notify the Unions within one week the names of men whom they propose to transfer and will afford each man an opportunity of having an advocate to present his case to the general manager.

5. The settlement shall not extend to persons who have been guilty of violence or intimidation.

The unions instructed their members that there must be no intimidation or interference with loyal staff. The Company responded by asking that nothing should be done on their side to cause ill-feeling and by applying the settlement in a generous spirit. The situation called for good will on both sides. General trade was in a bad state. The coal strike was clearly going to drag on. In order to save fuel the passenger service had to be cut down to 50 % of normal. It looked as though 25 % of the strikers could not hope for re-employment. The unions appealed to the Companies to help them through the difficult period which lay ahead, and on 21 May an agreement was signed for the temporary suspension of the guaranteed week. This arrangement does not apply to men who remained loyal. Employment will be found for as many of the strikers as possible by distributing work on a basis which will give three day's ordinary pay to each man re-engaged. In other respects the existing national agreements remain in force. Truly a sorry ending to the great adventure from the point of view of the railwaymen !

The cost of the strike to the London & North Eastern may be put at the round figure of £1 000 000. This estimate allows for the loss in gross receipts and for the saving in wages which were not paid to the strikers. It also takes into account expenditure on volunteers

and on a handsome bonus which is being given to loyal staff. It does not include anything for consequential losses which may arise from the fresh impetus given by the strike to motor competition.

Heavy as the loss to the Company and its employees has been, there are compensating gains. The trades unions have given up all faith in the policy of a general strike. Their defeat has been a triumph for constitutional procedure as a means of settling industrial disputes. Since 1911 the country has been unsettled by a series of strikes. Nearly every trade has been involved at one time or another. Owing to economic conditions most of the strikes ended in concessions to the workmen. Now the greatest strike of all has emptied the coffers of the unions and must have shown their members that they have to face a new set of circumstances. Much hard work will be needed to make good the ground lost by the stoppage, but encouraging reports have come to hand which prove that the railwaymen are putting their best foot foremost. Their leaders have urged them to give to the Company of their best and to observe the letter and spirit of the agreements into which they have entered.

MISCELLANEOUS INFORMATION

[625 .142.4]

1. — Notes on ferro concrete sleepers,

By Count BORINI.

Figs. 1 to 3, p. 72 and 73.

(*Rivista dei Trasporti.*)

Rectangular sleepers have been used generally up to the present, and care has been taken when laying them to see that the ends are properly supported by thoroughly consolidating the ballast under the rail bearing plates, the ballast being left just clear of the sleeper at the centre (see fig. 1). The reason for this will be appreciated when it is remembered that the ends of the sleepers may be considered as two bearings through which the loads on the rails, due to the passage of rolling stock, are transmitted to the ballast, the centre part acting as a rigid connecting tie rod. In practice there is noticed, in addition to the lowering of the level due to ordinary compression, a further lowering caused by the ballast under the sleepers tending to get away, it might even be said being forced out, from under the ends of the sleepers, the result being that the ballast gradually loosens.

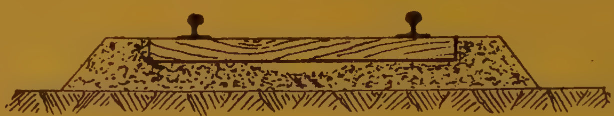


Fig. 1.

Fig. 2.

The final result is that the sleeper becomes supported in exactly the opposite way to that aimed at when laying it (see fig. 2).

In the case of wood sleepers, this defect may be remedied by tamping the ballast under the ends before slightly raising the height of the sleeper. No damage has been done to the sleeper through being supported at its centre for a time as, owing to the high elastic strength of wood, a considerable bending moment can be carried at the centre which is just where it acts.

Obviously this is not the case with ferro concrete sleepers as their elasticity is much lower than that of wood. The extended trials made between 1910 and 1912 by the Italian State Railways of more than 300 000 ferro concrete sleepers with the original special bearing plate proved this point. The main breakages occurred chiefly at the middle of the sleepers, whilst others, though less numerous, were found to have occurred at the rail fastenings, due to many causes, amongst which must be mentioned the dynamic effect of shocks.

In order to overcome the above-mentioned defects, it would seem that the sleeper used should be of such form that it would :

1) Resist the considerable bending moment which occurs at the centre when, for any

reason, the ballast becomes loose at the ends. With this object in view, the depth of the sleeper at the centre must be sufficient for its moment of resistance to be equal, or approximately so, to the bending moment mentioned above;

2) Maintain the best possible contact with the ballast by specially shaping the underside of the sleeper, and by using, in place of ordinary ballast, ballast of carefully selected size.

In addition, the effect on the sleeper of dynamic forces must be reduced to a minimum by using special fastenings on an elastic packing which would absorb, or, at least, limit the vibrations and shocks caused by passing trains.

These rules, which are opposed to those now in use when wood sleepers are under consideration, together with more than twenty years' experience, have enabled us to design a special elastic bearing plate, in metal or wood, on which the rail would rest, with a special method of fastening, using metal ferrules and fang bolts, as well as a sleeper of quite special form, so designed that it maintains practically permanent equilibrium on the formation with regard to the rail supports (see fig. 3).

Fig. 3.

Sleepers of this pattern with this method of fastening have been in use for nearly three years on the main lines of the Reggio-Guastalla Railway, and have given results which have confirmed the principles enunciated above. The Italian State Railways will shortly test them on a large scale.

It is not suggested that this improvement in the shape of the rigid sleeper has solved this difficult problem : it is felt however that progress has been made towards a solution.

The sleeper, 2.40 m. (7 ft. 10 1/2 in.) long, weighs about 220 kgr. (485 lb.) with 15 to 24 kgr. (33 to 53 lb.) of metal reinforcement, and its cost price is high (65 to 70 lires) ; if a good durable sleeper is wanted it cannot be made cheaper unless the prices of steel and cement fall.

Owing to the continued increase in the cost of wood sleepers, concrete sleepers will in the end have to be used for reasons of economy due to their longer life and the saving in the cost of upkeep of the track their use effects.

A number of sketches of the sleeper in position are given above so that the theoretical considerations underlying the laying of sleepers and their behaviour in service may be more readily understood.

[656 .255 (.944) & 656 .256.3 (.944)]

2. — Automatic crossing loops on single lines.

Fig. 4, p. 74

(*Railway Gazette.*)

It is now a well-recognised fact that the provision of automatic signalling installations, in lieu of manual signalling is not only safer, but in the long run productive of a definite economy. This applies not merely in the case of districts having a high train density, but also in relatively light traffic districts where there are special circumstances warranting the elimination, as far as possible, of the human element. Such a situation arises in

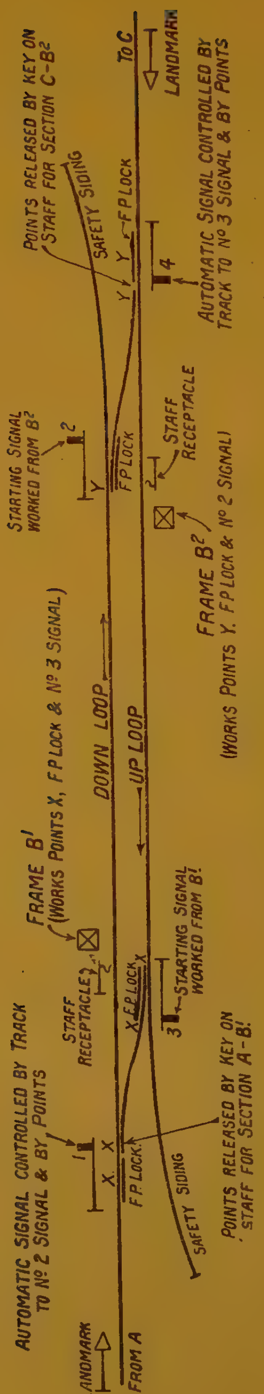


Fig. 4. — Plan showing signalling at automatic crossing loop.

New South Wales, where, owing to the high rate of wages paid to railwaymen, it is essential for the administration to strain every effort to keep down the number of men employed.

Under the old conditions it was necessary for three officers to take duty in eight-hour turns at crossing stations on single lines, but since the development of the unattended automatic crossing loop (the arrangement having been devised by the chief traffic manager in conjunction with the signal engineer) it has been found possible to eliminate the human element entirely, except in special circumstances.

The arrangement has been installed at a number of crossing loops on less important branch lines where the traffic is relatively light, and such loops can be worked entirely by the trainmen themselves without sacrificing any features of security. The average time taken to pass a train through an unattended crossing loop is seven minutes. It has also been installed on important main lines and, in this case, an officer is brought on duty for the passage of certain express trains, the working being attended to by the train crews for all other trains. A slight modification to the circuits is arranged, under these conditions, so as to give a through run to an express train when required.

In the lay-out of an unattended automatic crossing loop security for trains approaching from opposite directions is afforded by the provision of a dead-end siding at the outgoing end of each loop. Taking one loop as an example — a fixed distant signal or landmark is provided, it not being necessary to work a distant signal owing to the fact that every train must come to a stand at the crossing loop. At the single line facing points at either end an automatic home signal is provided. This is controlled by track circuit up to the end of the crossing loop, and also by the points at either end when in their normal position. The signal will, therefore, clear automatically when the crossing loop is clear, and when both points are lying in their normal positions. At either end of the crossing loop is a small ground frame, in

which is placed the electric staff instrument for the adjacent section, this staff instrument being arranged to work automatically. From this frame are worked the facing points between the loop and the main line, and the signal for leaving the loop. The lever working the points is released by the insertion of the staff for the adjacent single line section, the staff, however, being released for use when the points have been moved.

In cases where the traffic is very light, in order to effect a saving in the battery consumption, which would otherwise be necessary for holding the home signal in the clear position continuously, the arrangement of the track circuits is so modified as to cause the signal to resume the clear position (subject, of course, to the loop being clear) upon the approach of a train within sighting distance of the signal.

The procedure in connection with passing a train through the loop is as follows :

A train arrives from the direction of *A*, and provided the previous train has cleared the down loop, the driver finds the automatic signal at clear for him to run into the loop. As he passes the ground frame, the driver places the staff in a receptacle or upon a hook adjacent to the frame, and brings his train to a stand at the starting signal at the opposite end. On the train coming to a stand, the guard alights, takes the staff and restores it to the instrument in frame *B.1*. In the meantime, the fireman proceeds to frame *B.2* and withdraws the staff for the forward section *B.2c*. He then inserts this staff in the locking frame at *B.2*, and by this means the points are released. The points are then set, and signal *2* cleared, and the train passes out on to the single line in the direction of *C*, the fireman taking the staff to the driver. Immediately the train clears the points, the guard resets the points in their normal position and joins the train, which then proceeds on its journey. The accompanying diagram shows a typical automatic crossing loop.

By this scheme it will be seen that there is full security against a train entering an occupied loop, and also against a train being turned out on to a single line as one is approaching. This latter security is afforded by the fact that the points are released by the train staff, which, of course, would be in the possession of the approaching train. Upon a line on which the traffic is not heavy, the delay arising in consequence of the guard having to walk from one end of the loop line to the other is not serious, whilst the saving in expenditure effected is, of course, very considerable.

In the event of the electric train staff instrument failing, special arrangements are made whereby, under suitable precautions, the points of the loop line can be worked by the pilotman in charge of single line working.

Quite a number of these installations have been effected, and as they are giving entire satisfaction — as we can testify from personal experience — the arrangement is being extended as rapidly as possible to other suitable locations.

[621 .132.3 (.43) & 621 .132.5 (.43)]

3. — Standard locomotives for the German State Railways.

Figs. 5 to 10, pp. 77 to 79.

(From *The Railway Engineer*.)

For very many years past there has been in operation on the railways of Germany a multiplicity of locomotive types, this being mainly due to the independence of the railway administrations of the various Federal States, and with the amalgamation of the railways and the organisation of the system as a unified scheme this highly uneconomic condition of affairs was regarded as one of the principal matters calling for alteration.

Any process aiming at the substitution of a widely-diversified locomotive stock by a fewer number of standardised types must of necessity be somewhat slow in its development, but the matter has been taken definitely in hand, and some of the new standard locomotives have already been completed and placed in service, whilst others of a highly advanced classification, with the heaviest adhesion load yet applied in Germany, are ready for introduction and will be placed in service as soon as the necessary strengthening of the bridges and track on certain sections have been completed.

One of the types particularly referred to is a 4-6-2 express locomotive, which for the purpose of comparison has been built in two different forms, namely, two-cylinder single-expansion and four-cylinder compound. Another is a heavy freight engine of the 2-10-0 type. This was also built in two different forms : two-cylinder and three-cylinder single expansion. These locomotives have been constructed by various leading firms in Germany, those of which illustrations are given here having been built by Henschel & Son, of Cassel. The Pacific type engine is, in this case, of the compound, four-cylinder pattern.

Any system of locomotive standardisation would be largely ineffective unless steps were taken to ensure, so far as is possible, interchangeability of parts, for without this the main value of standardisation is lost. Interchangeability is in this case reflected in an economy of time and labour in effecting repairs and also making it unnecessary to hold very extensive stocks of component parts. The German locomotive builders have, as a consequence, and with the co-operation of the Central Railway Administration, brought into being a technical office where the designs of the new State Railway locomotives on standardised principles have been worked out. These principles apply both to a certain uniformity in respect of the various types of locomotives and to the interchangeability of as many parts as possible. In each type of locomotive all spare parts are produced in accordance with uniform tolerance gauges and templates, with the result that all such parts can be fitted to any of the standard locomotives without necessitating subsequent work and irrespective altogether of the particular factory in which the locomotive was built. This interchange in fitting is only possible by the aid of very accurate measuring and testing appliances.

The standard Pacific type engine.

One of the most notable features of this locomotive is the fact that the axle loading is now approximately 20 tons, which is to become the standard in place of 17 1/2 tons hitherto used. For this reason, therefore, the power output of the locomotive will be proportionately greater than others having the same wheel arrangement, and it may here be pointed out that these new locomotives have been designed to handle 60 axle trains which were beyond the capabilities of the six-coupled engines previously employed in fast passenger service.

The new engines present many novel features, amongst them being bar frames, which are to be uniformly employed in all the standard types in future. These frames are formed from rolled-steel plates 100 mm. (3 15/16 inches) thick, whereas the ordinary plate frames previously used for German locomotives were 25 to 30 mm. (63/64 to 1 3/16 inches) in thickness. The reasons given for the adoption of the bar type of frame are improved accessibility of the inside parts and the ease with which a wide firebox can be used, thus obtaining a large grate surface without recourse to an excessive firebox length.

In order to maintain the continuous development of high power, a large boiler has been provided with a correspondingly larger heating surface. The diameter is 1 900 mm. (6 ft. 2 3/4 in.), and the length between the tube plates 5 800 mm. (19 ft 3/8 in.). The boiler barrel contains smoke tubes of 135 mm. (5 5/16 inches) diameter, arranged in five rows one over the other, for the reception of the large smoke-tube superheater of the Schmidt type, and also 129 fire tubes of 49 mm. (1 15/16 inches) diameter. The barrel carries a steam dome and a feed-water

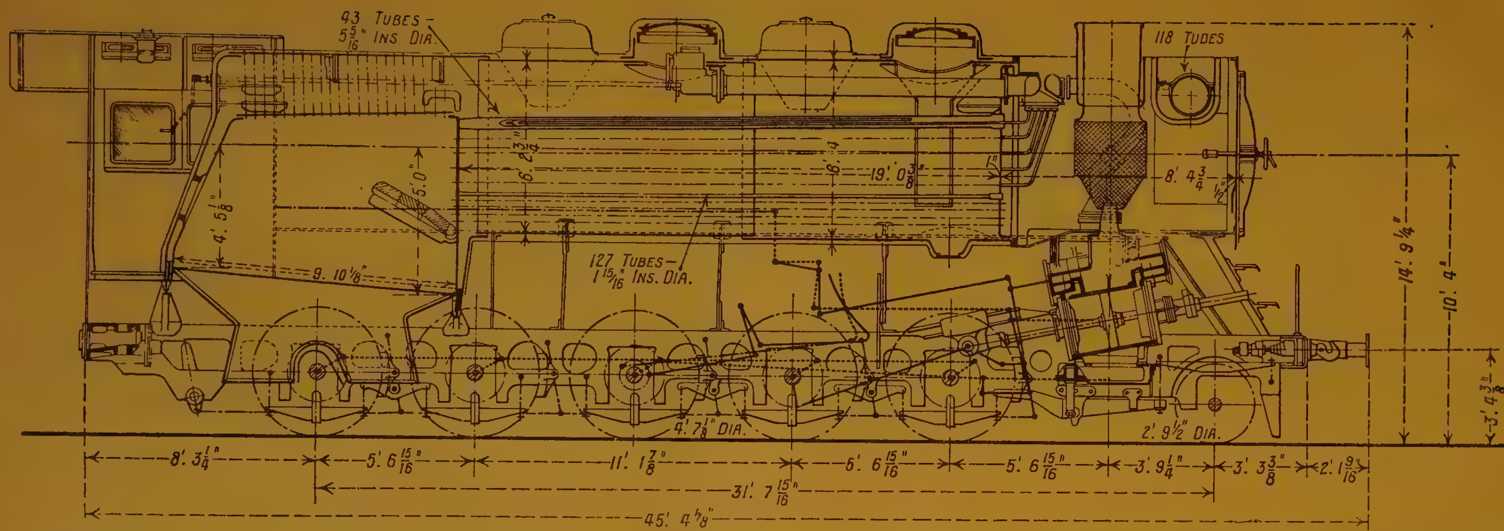


Fig. 5. — New standard four-cylinder compound 4-6 2 type express passenger engine for the German State Railways.

Fig. 6. — Bar framing with inside cylinder and boiler mountings for 2-10-0 type engines.

Fig. 7.

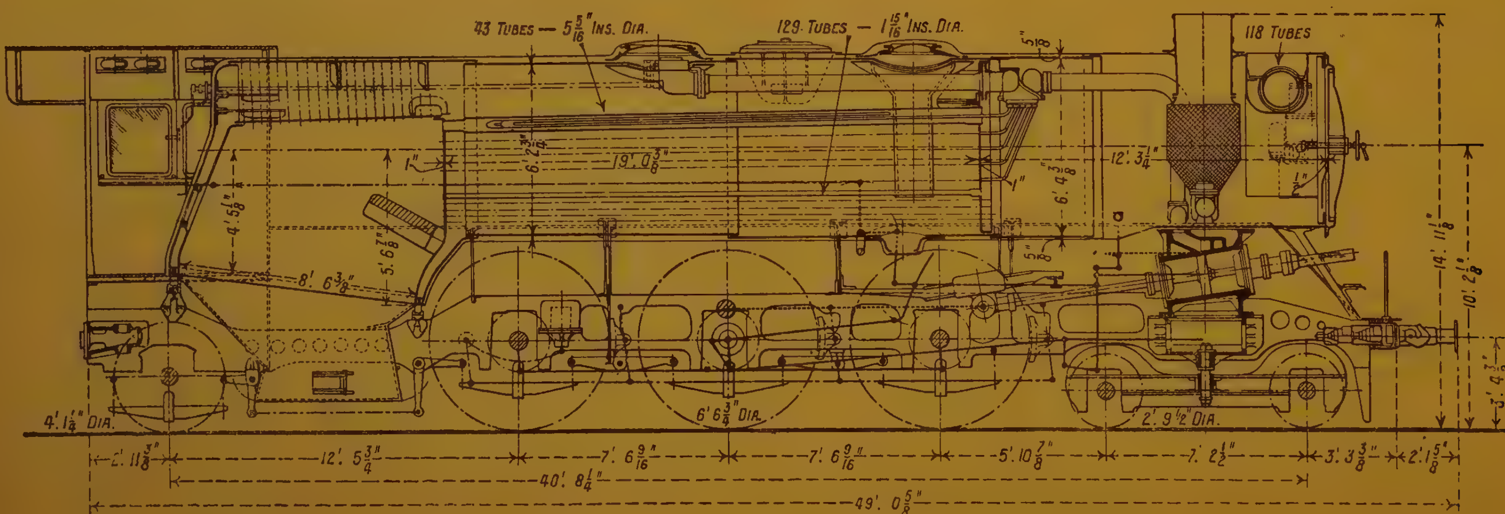


Fig. 8.

Figs. 7 and 8. — Standard three-cylinder simple 2-10-0 type heavy freight engine for the German State Railways.

mounting with angular grid water purifier. The smoke-box extends over the cylinder saddle, and the preheater is placed transversely above it in front of the chimney, whilst the air and feed pumps are placed to left and right of the boiler barrel, in order to give the enginemen as free a view as possible. The feeding of the boiler is effected by means of an injector and a Nielelock feed pump. The valves necessary for operating the injector, the steam-heating device, coal and ash-pan spraying devices, etc., are placed in a steam connection arranged on the left-hand side of the firebox, whilst the steam necessary for operating the air and feed pumps, the whistle and the blower is taken from a steam connection placed on the left-hand side of the smoke chamber.

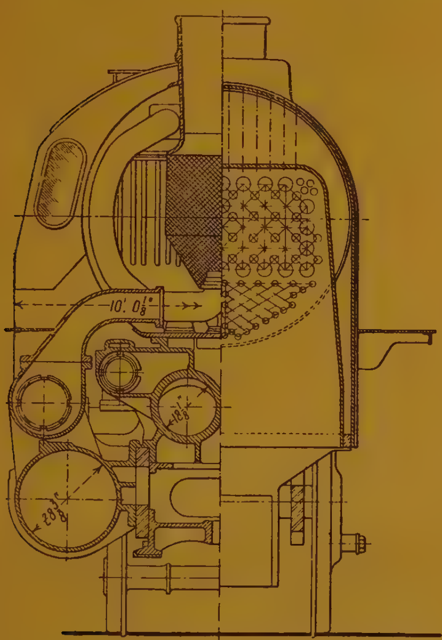


Fig. 9. — Half sections through cylinders and through firebox, 4-6-2 type.

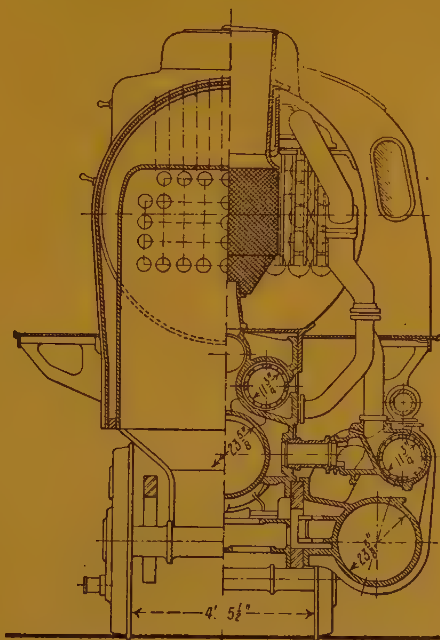


Fig. 10. — Half sections through cylinders and through firebox, 2-10-0 type.

The centre line of the boiler is 3 100 mm. (10 ft. 2 in.) above the rail level, this height being employed in order to obtain a sufficiently deep firebox. The result of this high centre line is reflected in the size and shape of the domes, sand-box, chimney and other fittings, the former being, as will be seen from the illustration, of reduced height. The extension shown on the chimney is permissible only on certain sections of the road. The dome next the firebox contains the throttle or regulator valve, which is of the well-known Schmidt & Wagner type, whilst that in front of the sand-box contains the feed-water purifier working in connection with the Knorr feed-water preheater, which is fitted transversely in the smokebox immediately in front of the chimney. The feed-water is heated to about 100° C. (212° F.), and upon entry into the feed-water dome it is broken up into spray-like form, when owing to its mixing with the steam in the steam space, it is further heated to about 135° C. (275° F.), at which temperature the scale-forming particles are separated and de-

posited on a series of trays, from whence they are conveyed by means of rectangular ducts, formed round the inside periphery of the boiler barrel, into a sump, which can easily be blown out after each trip through a valve fitted specially for this purpose. The purifying trays are removable for cleaning. In addition, a blow-off cock is provided at the back of the boiler, and here are no fewer than 32 mud doors. The condensate from the preheater is returned to the tender tank after having first passed through an oil separator. In this manner about 15 % of the water evaporated in the boiler is passed back to the tank as clean, hot water, and, of course, free from scale deposits.

Contrary to ordinary practice, the various fittings for supplying steam for the injector, steam heating, feed-water and air pumps are located outside the cab, and with a view to avoiding long pipe connections, one steam turret is placed on the firebox in front of the cab, and another forward on the left-hand side of the smokebox. The fire grate is fitted with a drop portion operated by hand by means of a wheel and screw. The ashpan is provided with the necessary dampers, as usual, and, in addition, with easily manipulated ash hoppers.

The construction of the superheater header in the smokebox is peculiar, inasmuch as the saturated and superheated sections are separate castings bolted together. This construction has for its object the eliminating of fractures which might arise from the stresses set up by the difference in the temperature of the sections for the saturated and superheated steam. The feed-water pump and the air brake are arranged at either side of the smokebox.

The engine, as seen, is fitted with wind guides, these being for the purpose of deflecting the smoke upwards when the engine is running, thus preventing it from beating down, and in that way obstructing the view from the cab.

In order to ensure the safe negotiation of curves, the leading truck is constructed on the Adams principle, allowing for lateral motion, and the trailing pair of wheels is ar-arranged in the same manner. Further, so that the engine may run steadily on straight portions of the track, strong leaf or laminated check springs control the lateral motion of the leading truck, whilst that of the trailing truck is effected by helical springs. The diameter of the coupled wheels is 2 000 mm. (6 ft. 6 3/4 in.), which enables the locomotive to attain a speed of 120 km. (74.6 miles) per hour.

The centre lines of the two high-pressure cylinders placed between the frames are inclined. These cylinders form one casting with their respective steam chests. The low-pressure cylinders placed outside the frames are horizontal.

Steam distribution is effected by means of piston valves with small spring packing rings. The high-pressure valves of 220 mm. (8 11/16 inches diameter) have inside admission, and the low-pressure valves of 350 mm. (13 3/4 inches diameter) outside admission. They are actuated by the standard Walschaerts valve gear with transmission shafts for conveying motion from the outside to the inside valve spindles. On the steam chests are bye-pass valves controlled by air, and on the cylinders the usual drain valves and safety valves. The high-pressure bye-pass valves, when open, also serve as starting gear, the steam flowing direct through the steam chests of the high-pressure cylinders to the low-pressure cylinder. In the case of the two-cylinder locomotive, the cylinders measure 25.6 inches diameter by 25.9 inches stroke, and the piston valves are 11 3/4 inches diameter.

The following are the leading dimensions :

Cylinders (two) H. P. diameter	460 mm. (18 1/8 inches).
— (two) L. P. diameter	720 mm. (28 3/8 inches).
— piston stroke	660 mm. (26 inches).
Wheels, coupled, diameter	2 000 mm. (6 ft. 6 3/4 in.).
— bogie, diameter	850 mm. (2 ft. 9 1/2 in.).
— trailing, diameter	1 250 mm. (4 ft. 1 1/4 in.).

Wheelbase, rigid	4 600 mm. (15 ft. 1 1/8 in.).
— total	12 400 mm. (40 ft. 8 1/4 in.).
Steam pressure	16 kgr. per square centimetre (227.6 lb. per square inch).
Heating surface :	
Firebox	17 square metres (182.99 square feet).
Tubes	221 square metres (2 378.91 square feet).
Total	238 square metres (2 561.90 square feet).
Superheater	100 square metres (1 076.43 square feet).
Preheater	13.4 square metres (144.24 square feet).
Grate area	4.5 square metres (48.44 square feet).
Weight in working order (engine)	111.50 tons.
Adhesion weight	59.28 tons.
Weight in working order (engine and tender)	175.56 tons.
Tractive power	26 400 lb.

Tender.

Wheels, diameter	1 000 mm. (3 ft. 3 3/8 in.).
Wheelbase, total	4 750 mm. (15 ft. 7 in.).
Water capacity	6 600 imperial gallons.
Coal capacity	6.9 tons.
Weight in working order	64.062 tons.

All wheels of the coupled axles and also those of the bogie are braked on one side by air brakes of the Knorr type, the brake power available being equal to 170 % of the adhesive weight and 70 % of the weight borne by the trucks. The tender is equipped with a Kunze-Knorr pressure brake, as well as hand brake. Furthermore, the driving and coupled wheels are sanded by means of an air sand blower. The locomotive also possesses steam-heating apparatus, gas lighting and speed-indicating mechanism. The tender is carried on eight wheels, the leading pair of axles being mounted in a bogie, whilst the trailing pair are rigid with the main frames.

The 2-10-0 type heavy freight engine.

The standard heavy freight engine of the 2-10-0 type with three single-expansion cylinders represents the latest and largest develcpment of its kind in Germany. As the drawing shows, the inside cylinder is inclined and drives the second pair of coupled wheels, whilst the outside cylinders are horizontal and drive the third pair of coupled wheels. The boiler is substantially the same as that fitted to the passenger engine previously described, as also is the general equipment of the locomotive.

Steam distribution is effected by piston valves 11 3/4 inches in diameter, the inside valve being actuated by mechanism deriving motion from the outside valve spindles. The arrangement of steam and exhaust piping is shown in the cross-end sectional view, which similarly demonstrates the location of the steam chests to the cylinders. The latter are 23 5/8 inches diameter, the piston stroke being 26 inches, other particulars being as follow :

Heating surface total	2 551 square feet.
Superheater	1 076 — —
Grate area	50.6 — —
Working pressure	200 lb. per square inch.
Weight in working order	111.65 tons.
Tractive power	47 100 lb.

The tender is mounted upon two four-wheeled bogies, with wheels 3 ft. 3 3/8 inches in diameter. It has a coal capacity of 9.842 tons, and a water capacity of 7 000 imperial gallons. Its weight in working order is 75.22 tons, making a total for engine and tender together in working order of 186.87 tons. Further particulars can be obtained from the drawings.

4. — Statistics of the Roumanian

We reproduce below a table giving statistics of train

Length of system : 6 955 miles.

Traffic statistics of

Type of trains.			From or to Bucharest	Number of trains run.	Trains booked.	Trains actual.	Delay.	Train.	Engine.[1]	Luggage vans.	Mail vans.
				Numbers.	Hours in traffic.		%	Miles.			
b			i	j	k	l	η	m	o	p	q
TAXED TRAINS.		Express trains de luxe.	from	1 627	23 309	23 713	2	570 809	622 570	1 742 173	1 435 532
			to	1 773	2 503	22 937	2	574 766	642 748	1 740 537	1 438 761
		Fast.	from	10 091	75 169	77 007	2	1 628 817	1 734 559	4 553 555	3 698 735
			to	10 492	74 939	76 962	3	1 630 250	1 723 385	4 565 068	3 585 974
		Slow and special.	from	48 152	262 871	266 621	1	4 212 682	4 304 463	10 573 641	7 638 417
			to	49 568	260 595	265 395	2	4 214 877	4 320 080	10 480 210	7 921 149
		Mixed.	from	87 202	214 790	222 349	4	2 238 037	2 256 205	4 559 750	2 133 514
			to	91 951	210 813	216 549	3	2 238 386	2 254 703	4 550 279	2 157 028
		Autotrains.	from	2 236	6 429	6 664	4	115 557	115 557	6 439	2 612
			to	2 544	6 144	6 443	5	115 232	115 232	7 376	3 460
	Goods.	Fast.	from	2 027	58 398	61 125	5	581 138	607 807	...	...
			to	2 240	59 173	63 002	6	584 372	614 595	...	...
		Through, pick-up and ordinary.	from	97 816	812 896	857 114	5	5 970 155	6 355 022	174	850
			to	102 438	806 428	861 963	7	6 013 315	6 457 245	56	260
		Special rated.	from	939	5 545	5 620	1	38 952	39 099	...	...
			to	909	4 415	4 419	0	33 376	33 589	...	...
		Total taxed trains.	from	250 090	1 459 407	1 520 213	4	153 356 147	16 035 283	21 435 732	14 909 660
			to	261 915	1 445 010	1 517 670	5	154 404 574	16 161 577	21 343 526	15 106 632
FREE TRAINS.		Military.	from	240	2 232	2 254	1	20 279	21 525	2 064	...
			to	344	3 063	3 107	1	29 912	32 181	2 451	...
		Royal.	from	38	265	266	0	5 313	6 575	31 826	...
			to	36	202	204	1	4 588	5 786	31 389	...
		Special ministerial and autotrains.	from	89	278	278	0	5 038	5 351	13 899	...
			to	98	335	346	3	5 912	6 187	12 487	...
	Administrative.	Staff.	from	30 127	13 882	15 329	1	203 172	208 076	86 924	9 436
			to	29 731	12 936	14 204	10	185 863	187 806	76 939	9 392
		Maintenance.	from	8 240	25 004	25 664	3	150 712	152 123	2 001	...
			to	8 405	24 191	24 622	2	159 483	160 385	2 683	...
		Test.	from	1 098	3 003	3 192	6	39 498	39 524	30 995	19 801
			to	1 158	3 131	3 336	7	41 658	41 691	31 048	19 597
		Breakdown and snow ploughs.	from	93	242	242	0	2 061	2 061	43	43
			to	96	233	231	0	2 046	2 046	43	43
		Light engines.	from	35 377	26 632	27 034	2	...	382 008	...	...
			to	36 422	29 119	29 508	1	...	424 109	...	...
		Total free trains.	from	75 302	71 538	74 259	4	426 073	817 243	167 752	29 280
			to	76 290	73 210	75 558	3	429 462	860 191	157 040	29 032
Total general.			from	325 392	1 530 945	1 594 472	4	15 782 220	16 852 526	21 603 484	14 938 940
			to	338 205	1 518 220	1 593 228	5	15 834 036	17 021 768	21 500 566	15 135 664
Total general.			Accumulated.	663 597	3 049 165	3 187 700	5	31 616 256	33 874 294	43 104 050	30 074 604
Daily average.			Accumulated.	1 818	8 354	8 733	5	86 620	92 806	118 093	82 396

ilways for the year 1925.

vements on the Roumanian Railways for the year 1925.

Roumanian system. *Total of standard and narrow gauge lines.*

Axles				Total	*Luggage vehicles, mail vans, passenger, sleeping and dining cars.*	*Goods and miscellaneous wagons.*	*Engines not in steam.*	Total
assenger vehicles.	*Sleeping and dining cars.*	*Goods and miscellaneous.* empty.	*Goods and miscellaneous.* loaded.	columns *p, q, r, s, t, u.*				columns *w, x, y.*
Miles.				Axle-miles.	100 gross ton-miles.			
r	*s*	*t*	*u*	*v*	*w*	*x*	*y*	*z*
7 328 561	4 816 372	36 457	61 015	15 420 110	1 547 173	7 564	...	1 554 737
7 306 048	4 876 362	24 272	79 313	15 465 293	1 542 422	7 796	...	1 550 218
3 109 402	5 527 602	214 458	208 316	42 312 068	3 976 740	26 550	...	4 003 290
7 997 888	5 574 461	175 978	328 286	42 227 655	3 950 493	32 596	98	3 983 187
1 311 419	879 948	766 805	3 499 765	94 669 995	8 122 088	294 413	1 365	8 417 866
1 259 416	876 317	989 460	3 740 628	95 267 180	8 200 115	319 651	313	8 520 079
0 742 776	60	7 579 860	9 770 057	44 786 017	1 924 103	1 172 333	290	3 096 726
0 614 453	...	6 086 937	12 224 324	45 633 021	1 924 545	1 339 655	7 355	3 271 555
659 696	...	104	332	669 183	46 490	31	...	46 521
669 835	...	731	565	681 967	46 279	76	...	46 355
161	...	10 167 227	18 156 357	28 323 745	405	2 053 081	595	2 054 081
...	...	6 353 620	22 379 594	28 733 214	433	2 250 682	1 644	2 252 759
35 907	121	140 162 940	193 891 227	334 091 219	10 941	25 308 385	10 327	25 329 653
33 064	149	96 746 863	236 070 966	332 851 358	11 028	28 236 899	13 851	28 261 778
15 311	...	908 018	779 202	1 702 531	768	98 207	...	98 975
18 032	...	523 233	978 139	1 519 404	884	104 813	...	105 697
8 203 233	11 224 103	159 835 869	226 366 271	561 974 868	15 628 708	28 960 564	12 577	44 601 849
7 898 736	11 327 289	110 901 094	275 801 815	562 379 092	15 676 199	32 292 169	23 261	47 991 629
212 333	...	188 457	941 732	1 344 586	14 274	74 090	...	88 364
214 446	...	259 183	1 561 677	2 037 757	15 125	123 407	...	138 532
98 661	21 469	81	10 807	162 844	14 052	1 050	...	15 102
90 363	20 632	...	11 605	153 989	12 798	1 072	...	13 870
61 735	4 782	2 328	10 043	92 787	6 908	897	...	7 805
101 318	2 793	639	8 624	125 861	10 099	733	...	10 832
1 697 707	12 792	45 796	91 599	1 944 254	138 899	9 690	...	148 589
1 593 528	12 475	42 838	90 590	1 825 762	131 612	9 151	...	140 793
3 543	...	1 307 858	2 796 952	4 110 354	318	279 776	...	280 094
4 466	...	2 464 869	1 929 011	4 401 029	685	256 513	37	257 235
365 685	23 727	931 157	155 625	1 526 990	38 905	63 792	...	102 697
390 762	24 892	992 030	72 270	1 530 599	42 223	58 609	63	100 895
2 347	...	1 445	13 999	17 877	196	1 188	4	1 388
1 991	...	2 015	14 724	18 816	162	1 465	148	1 775
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...
2 442 011	62 770	2 477 123	4 020 757	9 199 693	213 552	430 483	4	644 039
2 396 874	60 792	3 761 574	3 688 501	10 093 813	212 734	450 950	248	663 932
0 645 244	11 286 873	162 312 992	230 387 028	571 174 561	15 842 260	29 391 047	12 581	45 245 888
0 295 610	11 388 081	114 662 668	279 490 316	572 472 905	15 888 933	32 743 119	23 509	48 655 561
0 940 854	22 674 954	276 975 660	509 877 344	1 143 647 466	31 731 193	62 134 166	36 090	93 901 449
714 906	62 123	758 837	1 396 924	3 133 280	86 934	170 231	99	257 264

[656 .254 (.73)]

5. — Radio phone between locomotive and caboose.

(From *Railway Age.*)

A practical demonstration of radio telephone communication between engineman in the locomotive cab and the conductor in the caboose of a 115-car freight train was conducted successfully on the New York Central on 8 July, between Chicago and Elkhart, Ind., a distance of 95 miles. The test was conducted under the auspices of Committee 12, Radio and carrier current systems, of the telegraph and telephone section of the American Railway Association, in conjunction with the Zenith Radio Corporation. In addition to members of the committee, communication officers of various roads were present to witness the tests making a party of about 60. The radio apparatus performed in a satisfactory manner throughout the run and it was the consensus of opinion among the railroad officers present that such a facility could be used to advantage in freight train operation especially in mountainous country.

The train with a load of 4 600 tons, consisting of 115 cars (62 loads and 51 empties the majority of which were steel hopper cars) 1 business car, 1 coach and 1 caboose, left Englewood, Sixty-Third street, Chicago, about 9.00 a. m., making the 95-mile run to Elkhart, Ind., in 4 hours 32 minutes.

The first use of the radio telephone apparatus was made while making up the train when the conductor talked with the engineman during the terminal air brake test and told him that there was not enough air at the rear end. At Pine, Ind., the engineman gave the conductor the number of the helper engine being attached and informed the conductor when he was ready to pull out. It was noted in this case that a period of 26 seconds elapsed between the time the engine started and the instant the caboose began to move. Orders had been issued to make a stop at Millers, Ind. However, it was decided that the requirements could be met by throwing off messages at this point, whereupon the trainmaster in the caboose told the engineman to disregard the order to stop at Millers, but to call to the attention of the operator at that station that messages would be thrown off the rear end. This procedure being carried out successfully the train stop was eliminated. Other information regarding the operation of the train was passed back and forth from time to time.

Equipment used.

The radio equipment used in the locomotive — the same as that used in the caboose — consisted of a combined receiving and transmitting set with a dynamotor set operating from a 12-volt storage battery for the plate voltage and a 12-volt battery for the filament. Seven tubes, three for transmitting and four for receiving, were employed, a wave length of 115 meters being used. The antenna consisted of about 35 feet of 1/2 inch brass pipe, which on the caboose was mounted on the frame work around the cupola, and on the engine above the cab roof.

The operation of the radio equipment was comparatively simple as was evidenced by the fact that the members of the train and engine crew, as well as a number of the railroad men present, had no trouble in securing satisfactory results. When ready for service the two sets are tuned; then by pressing a button in the caboose a howl was produced in the loud speaker in the engine cab. This signal was answered by the engineman by pushing a button and saying; « Engine 2561 talking, what do you want ? » This started the conversation. The receiver and transmitter of each set are mounted together in a portable style with a finger switch on the arm which is pressed when talking, this switch controlling the dynamotor which produces the transmitting voltage.

The howler signals which can be transmitted and received over the loud receivers at any time are used for calling a man to the phone, but can also be used to transmit the standard A. R. A .train operating signals such as for a « stop », « go-ahead », etc., that can be given by the signal air system on passenger trains.

These howler signals can be transmitted and received successfully under most any ordinary conditions. However, the speech transmission or reception was considerably reduced when the engine or caboose was passing through a long heavy steel bridge.

[656 .254 (73)]

6. — Loud speakers direct trains,

By Jesse A. LEASON.

Figs. 11 an l 12, pp. 85 and 86.

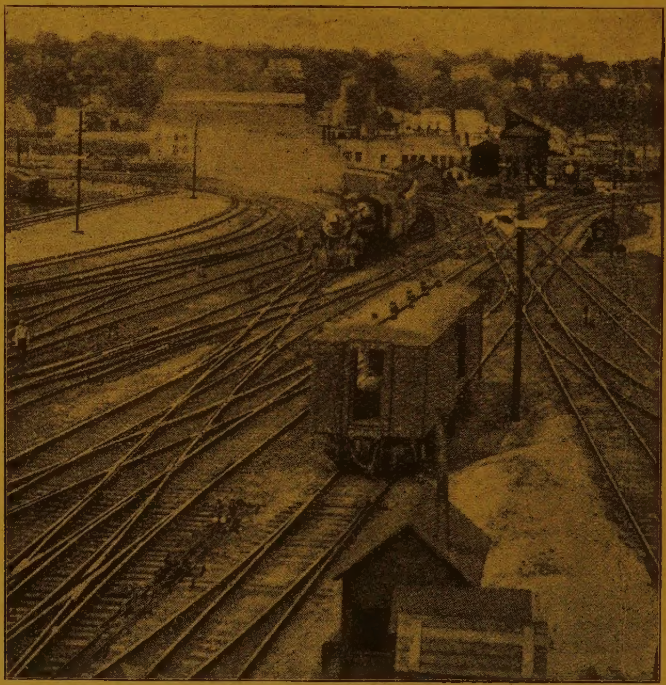
(*Railway Review.*)

Loud speakers and a microphone are being used successfully for the first time in the history of railroading to direct all train movements in the yards of the Union depot at St. Paul, Minn., and it is believed by transportation officials that the system will revolutionize the present method of handling trains throughout the country. After being in use only a few weeks the new system has demonstrated its worth by speeding up service, increasing efficiency in the yards and eliminating frequent misunderstandings of signals which occurred under the old method.

Fig. 11. — Switchman getting orders through loud speaker.

Trains coming into St. Paul approach on

the customary few lead-in tracks from which they are switched on to any one of twenty-three tracks leading into the depot. It is this switching which is handled over the loud speakers and switch tenders now receive their orders in spoken words instead of the manual or electric signal systems. Under the old method the train director in his tower gave his orders to switchmen by moving his arms to certains positions which the yardmen interpreted. In heavy rain or foggy weather it was often impossible to see the signal man



Fi. 12. — Approaeh tracks at St. Paul Union Station.

and even in clear weather it was easy to mistake the signals. Because of their complexity new men required weeks to learn the signals well enough to man their switches.

When an inbound train approaches St. Paul the director is informed by phone from outlying stations. He then assigns a track into the depot for the train and issues his orders into the microphone, giving the number of the train and the track it is to be directed over, the switchmen turning the proper switches as ordered.

Formerly it was not uncommon for several trains to be blocked outside the yards while trains inside were being untangled as a result of the failure of the old signal system. Delays for more than an hour have been known. Under the new method the trains move into the station with absolute precision, a delay of as much as two minutes being rare. There are twenty-nine loud speakers located throughout the yards and can be understood with perfect clearness. The loud speaker system was devised by J. Russell, superintendent of the St. Paul union depot and was installed at a cost of $6 000.